ROORKEE TREATISE on CIVIL ENGINEERING

SECTION IV.

EARTHWORK.

NINTH EDITION.

REVISED BY

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United Provinces.

(Reprint)

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PREFACE TO THE ROORKEE TREATISE ON CIVIL ENGINEERING IN INDIA.

The Roorkee Treatise was originally compiled by Lieutenant-Colonel J. G. Medley, R.E., in 1866 and issued in two volumes.

The Treatise grew out of the various College Manuals, dealing for the most part with subjects which required special treatment to suit the climate and methods used in India, and has been constantly revised and re-written. It is found advisable now to publish the Treatise in separate sections, so that each section can be re-written or revised and brought up-to-date whenever opportunity occurs, to keep pace with modern methods and discoveries.

The Treatise now contains the following sections: –

Section	I.	Building materials	1910
,,	II.	Masonry	1909
,,	III.	Carpentry	1910
,,	IV.	Earthwork	1912
,,	V.	Estimating	1908
,,	VI.	Buildings	1911
,,	VII.	Bridges	1910
,,	VIII.	Roads	1911
,,	IX.	Railways	1908
,,	X.	Irrigation works	1909
,,	XI.	Sanitary Engineering	1908
,,	XII.	Water supply	1902
,,	XIII.	Drawing ... { Part I	1907
		,, II	1908
,,	XIV.	Surveying	1911

10th April, 1912. E. H. de V. A.

PREFACE TO SECTION EARTHWORK, FIFTH EDITION.

Since the publication of the Roorkee Treatise in sections, the chapter on earthwork has been reduced to smaller dimensions than this important subject seems to demand. The study of earthwork is not engrossing in itself, but, considering the large sums of money that have to be expended on this kind of work, a knowledge of the methods of carrying it out in an economical manner is most important to the Engineer. I have, therefore, with several additions, compiled the information contained in the older Treatises and other works, in order that the students may be able to make themselves better acquainted with this class of work.

F. D. M. B.

ROORKEE:
1st *June*, 1892.

PREFACE TO THE 1916 EDITION.

In revising this Manual I have tried, as far as possible, to keep to the original arrangement, but have made omissions and additions to bring the work up-to-date. Chapter VII "Earthwork on Hill Roads" was written by Colonel F. D. M. Brown, and was entered in previous editions as "Notes regarding Earthwork on Hill Roads, etc."

I wish to thank Mr. B. Darley, Executive Engineer, for the details he has given regarding excavation by the steam navy and carriage of earthwork by locomotives, these are entered in chapter III.

Chapter VIII.—Earthwork for canal distributaries was written by Colonel Clibborn in 1893 when he was Principal of the Thomason College, and was included in the Earthwork Manual as appendix II. This chapter has been considerably cut down as it included a great deal which refers more to irrigation than to earthwork. Four new appendices and an index have been added.

30*th March*, 1916. G. T. B.

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ROORKEE TREATISE.

Section IV.—EARTHWORK.

CHAPTER I.

GENERAL NOTES.

1. The term earthwork in its widest sense comprehends excavation in rock as well as in the looser materials of the earth's crust. It also includes embanking and puddling, but the construction of mud walls called "Pise work", and also of dry stone retaining walls belong rather to building, and details regarding their construction will be found in the masonry manual.

The mere digging or cutting into the earth is so commonly done that it seems to require neither skill nor explanation, but when the work is extensive, as in the making of canals, reservoirs, tunnels and the like, many expedients must be resorted to that might not occur to the inexperienced. These have been adopted that they may economise labour, time and money.

In some countries such as Europe and America the methods followed in carrying out the work are of little importance to the Engineer, for frequently the workman himself will contract for the whole job (either for a certain sum, or at a specified rate) and will hire his own labourers, find tools and materials, and carry through the work in the way that he thinks will be cheapest to himself.

In such a case, the duties of the Engineer are to set out the form of the work according to plans, and to see that it is correctly carried out. He need not concern himself with the methods of execution.

2. **Work by contract.**—The usual course of proceeding, when contractors for the work can be obtained, is for the Engineer to prepare his map or plan of the country, together with a correct profile or section, to scale, of the intended work, and to write out a specification explanatory of his drawings and plans stating (1) how the work is to be executed, (2) where the spare soil is to be deposited, (3) when the work is to commence, (4) what time will be allowed for its completion, (5) how and where it will be paid for, (6) what penalty will be incurred should the work be badly neglected, or not finished within the stated time, (7) whether

not to be trusted in permanently, as it is gradually destroyed by the action of air and excessive moisture, and by changes of weather, specially by alternate frost and thaw. The temporary additional stability however produced by adhesion is useful in the execution of earthwork, by enabling the side of a cutting to stand with a vertical face for a certain depth below its upper edge. That depth is greater, the greater the adhesion of the earth as compared with its weight; it is increased by a moderate degree of moisture, but diminished by excessive wetness. The following are some of its values:—

Earth.	Greatest depth of temporary vertical face.
Clean dry sand and gravel	0
Moist sand and ordinary surface mould, from ..	3 to 6 feet.
Ordinary clay	10 to 16 feet

It is on account of this temporary stability that the sides of cuttings where the soil is undisturbed in its natural position are generally made with a steeper slope than would be given to the same earth if dug out and formed into an embankment. By degrees the steep slope becomes covered with grass, etc., so that by the time it has lost its natural stability other conditions help to keep it firm.

7. **Angle of repose.**—The permanent stability of earth which is due to friction alone, is sufficient to maintain the side either of an embankment or of a cutting at a uniform slope, whose angle to the horizon is the angle of repose. This is called the natural slope of the earth, and is the lowest slope, which soil thrown down freely and loosely tends to assume and permanently to retain. The tangent of the angle of repose is the co-efficient of friction of the soil; and it is usual to describe the slope of earthwork by the ratio of its horizontal breadth to its vertical height, which is the reciprocal of the tangent of the inclination.*

* In describing the longitudinal slope of a road, a different usage occasionally prevails. Where a road is said to rise 1 in 20, properly speaking, it means that in a horizontal length of 20 feet the rise is 1 foot; and in designing a road and drawing the section of it, such would be the way of expressing the slope. But as it is usual in measuring the length of a road (unless the slope be very great), to lay the chain along the ground, whether or not it is absolutely horizontal, a rise of 1 in 20 has come to mean a rise of 1 foot in a length of road of 20 feet; that is, the slope is expressed by the ratio of the sine to the radius of the angle of inclination. This is not strictly correct; but it saves a tedious calculation of the horizontal line from the length of road surface; and, after all, the difference in this case is only between 20 feet and 19·975 feet (i.e., $\sqrt{400-1}$ foot) or $\frac{1}{4}$ inch; and a slope of 1 in 20 is far steeper than is usually met with in a flat country.

The following are the observed angles of repose or natural slopes of several kinds of soil :—

Earth.		Angle of repose.	Customary designation of natural slope.	Co-efficient of friction.
Dry sand, clay, and mixed earth ..	{ from ..	37°	1·33 to 1	0·75
	{ to ..	21°	2·63 to 1	0·38
Damp clay	..	45°	1 to 1	1·00
Wet clay	{ from ..	17°	3·23 to 1	0·31
	{ to ..	14°	4 to 1	0·25
Shingle and gravel	{ from ..	48°	·9 to 1	1·11
	{ to ..	35°	1·43 to 1	0·70
Peat	{ from ..	45°	1 to 1	1·00
	{ to ..	14°	4 to 1	0·25

The most frequent earth-slopes are those called 1½ to 1 and 2 to 1, corresponding to angles of repose of 33⅔° and 26½°, nearly. The presence of a small amount of moisture in the earth seems slightly to increase its friction; but any large quantity of moisture diminishes it, till the earth is reduced to a semi-fluid state. Hence, to insure frictional stability, provision must be made for draining off the water contained in the earth.

The properties* of earth with respect to adhesion and friction are so variable, that the Engineer should never trust to tables or to information obtained from books to guide him in designing earthworks, when he has it in his power to obtain the necessary data either by observation of existing earthworks in the same stratum, or by experiment.

8. The sides of cuttings (being natural solid earth) will of course stand a steeper slope than the sides of made banks, and slopes protected from the action of water by grass or pitching, will stand better than unprotected ones. The most dangerous condition for a slope is where water drains out of the adjacent earth through it. All these conditions have to be thought out in deciding what slope shall be adopted for any excavation or bank. One and a half to one is an ordinary average slope in average soil, but often, in a running canal, in fairly stiff soil, the water cuts the slope to a steeper angle than 1 to 1, and then it remains constant, while for a reservoir embankment both sides are sometimes made at as great a slope as 5 to 1.

9. **Properties of clay soil.**—The property of retaining water and forming a paste with it belongs specially to clays, which, however hard

* Rankine, Civil Engineering, pages 316 and 317.

when first dug, gradually soften and disintegrate by the action of the weather, and lose their frictional stability. Hence, slopes of cuttings through stratified clays vary from 2 to 1 to 3½ to 1. Alternate strata of clay and sand are generally considered the very worst for excavation, as the sand favours the access of the water while the clay prevents its escape.

10. **Stratified soils.**—All stratified materials occurring in layers inclining to the horizon in the same direction as the side of a cutting are liable to a slipping of one stratum on another. And as it is evident that when strata are not horizontal, (if a cutting be made through them) the dip must on one side or the other incline towards the cutting, it follows that horizontal strata are the most favourable for excavation.

11. **Properties of rocks.**—Rocks have generally a certain permanent cohesion; so that, when firm and sound, a cutting may be carried through them with nearly vertical sides. How far this cohesion is to be depended on is a question to be solved rather by observation of the rock in each case than by any general principles, having regard to its geological position, chemical composition, etc., for its mechanical properties may have little connection with these. Generally speaking, however, the cohesion of igneous rocks, such as granite, trap, quartz, etc., if they are not much fissured, may be trusted, and they may be left standing at very steep slopes. The sedimentary rocks, sandstone and limestone, whether compact or granular, if hard enough for building purposes, will stand with vertical or nearly vertical faces. Sandstone exists, however, of all degrees of hardness, and may require a slope as great as 1½ to 1; while chalk will stand at from ½ to 1 to 1½ to 1, the cohesion of the upper beds being greater than that of the lower. All argillaceous rocks, such as shale must be treated with great caution, for they are liable to soften by the action of the weather. Conglomerates—even with an argillaceous matrix—will stand well with a vertical face for moderate heights.

12. **Preservation of materials required for other works.**—In the execution of all kinds of earthwork the Engineer must be careful to preserve any material excavated that will be useful on other parts of the work. Thus, should stone be required for revetment walls or pitching, all suitable stone dug out should be stacked and paid for at a sufficiently high rate, to cover the extra labour thus entailed; otherwise, as in the case of a hill road, the contractors will be only too glad to throw it over the "khud" and obtain the contract for collecting it again for building purposes. In the same way, should clay be required for puddling purposes or as top-dressing of an embankment, all suitable clay dug

within a reasonable distance should be preserved; also surface soil for dressing the slopes, etc., etc. The Engineer, by thus using a small amount of forethought, will be able to make large savings in the cost of the work and possibly do it much better; as it often happens that suitable material in excavations, not retained for the special purpose for which it could have been utilized, may either not be afterwards obtainable, or only obtainable at a prohibitive price.

13. **Hints on the management of work.**—The following practical advice may be found useful in cases where excavation work is being done by petty contract and in soil of variable texture, such as is found in the construction of a hill road, for which an all-round rate is given. These contracts are given out by the chain, each contractor getting so many chains according to the number of men he is able to employ.

The first thing the contractor does, if left to his own devices, is to commence work along the whole of the piece allotted to him. He will dig out all the soft part and then ask for payment on account, at the all-round rate. It is impossible to measure such work properly, as you have not generally too large an etsablishment for the purpose. The contractor having been paid for the easy part of the work, often demands a higher rate for the remainder, or slacks off work, or bolts. Again, from want of funds, or on account of the unhealthiness of the locality at some particular time of the year, work on the road may suddenly have to be stopped. The confusion the measurements then get into can well be conceived when the ground is broken all along the line. The measurements, unless too liberal, are disputed, and the work is paid for far in excess of its value. When work is resumed, the hard rock, which generally underlies the surface, remains to be done, for which a higher rate is demanded, and from the broken nature of the ground measurements become guess-work; in which the new contractor is again the gainer. The consequence is that estimates are exceeded, and a great deal of blame is naturally laid on the Engineer in charge.

All such confusion can be prevented to a great extent by not allowing the petty contractor to start work on more than one or two chains at a time—according to the size of his gangs—and no new chain to be commenced without the written permission of the officer in charge, who should have satisfied himself that the first chains are finished, or so far done that the contractor wants employment for his men.

Some Engineers never complete the final dressing till the whole work given out to the contractor has been finished in the rough. This system looks at first sight the most economical, as no repairs have to be done.

It should however never be allowed, as there are often great difficulties in getting the final dressing done and the settlement of the accounts is certain to be most troublesome. The Engineer should endeavour to complete and clear up the accounts of each small portion as it is finished, and carry out all necessary repair work by separate agency. This will ensure better banks, give less trouble, and will generally be found to be the most economical plan.

14. Each contract agreement should contain severe penalties for starting new work without sanction. The number of chains should be given out to the different contractors, in proportion to their available labour; so that the work may progress uniformly, and not have little bits of unfinished work all along the line, which increases the task of supervision. In the event of the work being unexpectedly stopped, the measurement of the small incomplete portions are the only difficulties to be encountered. All complete portions having already been settled in full and requiring no further attention on resuming work, a minimum of difficulty will be experienced.

15. This principle can be carried out in all kinds of work. It will thus be seen how much toil, vexation, and loss an Engineer can save himself and his employers by a little arrangement and method in his work. No amount of instruction or reading will avail an Engineer unless he has the ability and the energy to think beforehand and arrange, so as to avoid the difficulties and losses which must take place, unless he prepares himself for any contingency which may arise in the work, and which experience teaches him to look for.

CHAPTER II.

MENSURATION AND SETTING OUT OF EARTHWORK.*

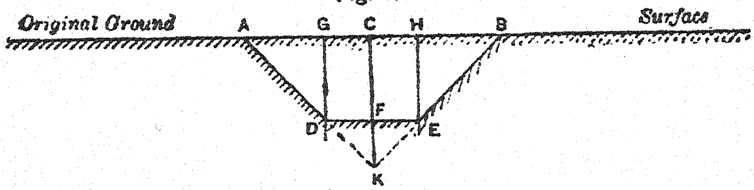
16. Earthwork rates are still comparatively cheap in India, and in the plains the ground is generally fairly level, so it is seldom necessary to use elaborate formulae for estimating or for measuring up the amount of earthwork done. In hilly or raviny country, where the excavation is through hard rock, or for broad surfaces such as the excavation of a reservoir, greater accuracy is necessary and the more complicated formulae which are given below in paras. 19 and 20 should be used. All formulae for estimating earthwork are based on geometrical figures, and these can only give accurate results if the ground surface varies in a series of planes but since the ground undulates in curves the application of any formula can only give approximate results. For this reason some Engineers add a small percentage to the total to allow for inaccuracies. When however careful levels are taken of the country there is seldom any necessity to make any such additions.

The best estimating system is that which gives practically accurate results with the least amount of labour and the fewest figures, and for this reason laborious calculations which entail a large number of figures are liable to cause mistakes and be less accurate.

The system explained in paragraph 23 is very simple, and is sufficiently accurate for all practical purposes, and is generally used by all Engineers.

17. In *Figs.* 1, 2 and 3 AB represents the ground surface which forms the top of a cutting or the bottom of an embankment.

Fig. 1.



* Most of the formulae in this chapter are taken from Rankine's Civil Engineering. For equations (3), (5), and (7), we are indebted to Ensign Keay, late Head Master, Upper Subordinate Class, Thomason College.

Fig. 2.

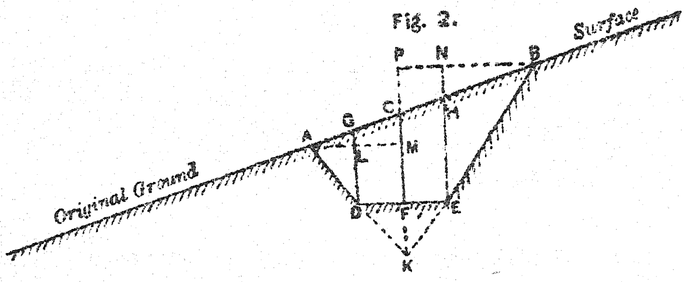
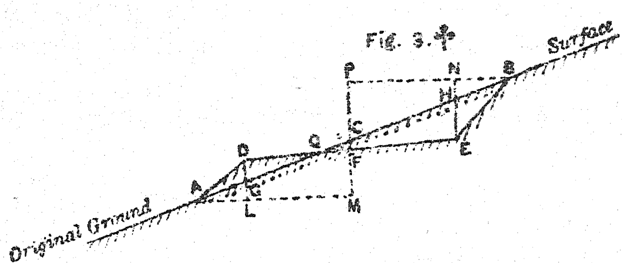


Fig. 3.†



DE represents the horizontal bottom of a cutting or the top of an embankment, and is called the base forming, or formation.

AD and BE represent the side slopes of the cutting or of the embankment, which connect the base with the original ground surface. The inclination of these slopes varies with the soil, the climatic conditions, and the nature of the work.

Figs. 1 and 2 represent sections of cuttings, the former through level ground the latter through sloping or "side-long ground" If they are turned upside down they will represent embankments.

Fig 3 shows a piece of earthwork, part of which QEB is in cutting, and the other part ADQ is embankment. C is a point on the centre line of the base of the earthwork; and the horizontal distances, AC and BC, in *Fig* 1, and AM and BP, *Figs.* 2 and 3, are termed half-breadths. It will be evident that only in *Fig.* 1 is C in the centre, and the half-breadths in reality equal to each other; for although the half-breadths of the base DF, FE, are in all cases equal and the same, the remaining portions, AL and BN, must vary with the slope of the ground, and must be determined by calculation.

18. **Side widths**—For this purpose the following formulae are given:—

In *Figs.* 1, 2 and 3 let the central depth of earthwork $CF=h$;

the half-breadth of the base $DF=FE=b$;

† In all these *Figs.*, DF must be equal to FE, and the slopes AD, BE, must be the same.

let s to l be the slope of the earthwork, that is, the ratio of horizontal feet to 1 vertical foot;

r to l, in a similar way, the slope of the side-long ground;

b' = horizontal half-breadth of the slope, that is BN on the upper side, and AL on the lower in Figs. 2 and 3, and BH and AG in Fig. 1.

I. Then in *Fig.* 1—

$$b' = sh, \ldots\ldots\ldots\ldots (1).$$

$$BC = b + b' = b + sh, \ldots\ldots\ldots\ldots (2)$$

II. In *Figs.* 2 and 3—

$$BP = r \times PC = s \times PK = s \times (PC + CF + FK)$$

$$\therefore PC\,(r - s) = s\,(CF + FK) = s\left(h + \frac{b}{s}\right) = b + sh$$

$$\therefore PC = \frac{b + sh}{r - s}, \text{ and } BC^2 = PC^2 + BP^2 = PC^2 + r^2\,PC^2$$

$$\therefore BC = PC\sqrt{(r^2 + 1)} = \frac{b + sh}{r - s}\sqrt{r^2 + 1}, \ldots\ldots\ldots\ldots (3)$$

which gives the actual distance to be laid off from C to the upper edge of the cutting.

Also BN^2 (or b'^2) $= BH^2 - NH^2 = BH^2 - \dfrac{BN^2}{r^2}$

$\therefore b' = \dfrac{BHr}{\sqrt{r^2+1}}$, and $BH = BC - CH$. But $CH^2 = FE^2 + \dfrac{FE^2}{r^2}$

$$\therefore CH = \frac{b\sqrt{r^2+1}}{r} \therefore BH = \frac{b + sh}{r - s}\sqrt{r^2+1} - \frac{b\sqrt{r^2+1}}{r}$$

and the half-breadth of slope $b' = \left(\dfrac{b + sh}{r - s} - \dfrac{b}{r}\right)r$

$$= \frac{rs}{r - s}\left(h + \frac{b}{r}\right) \ldots\ldots\ldots\ldots (4),$$

in which the factor $\left(h + \frac{b}{r}\right)$ = HE, the depth of earthwork at the edge of the base. In the same way on the lower side of a cutting, or the upper side of an embankment, in *Fig.* 2—

$$AC = \frac{b + sh}{r + s}\sqrt{r^2 + 1} \ldots\ldots\ldots\ldots (5),$$

$$\text{and } AL = b' = \frac{rs}{r + s}\left(h - \frac{b}{r}\right) \ldots\ldots\ldots\ldots (6).$$

where the factor $\left(h - \frac{b}{r}\right)$ represents the depth GD

When the ground intersects the base between the centre line and the edge of the earthwork, as at Q in *Fig.* 3, the values of BC and BN will be as in *Fig.* 2, found from equations (3) and (4),

Also $$AC = \frac{b - sh}{r - s}\sqrt{r^2 + 1} \ldots\ldots\ldots\ldots (7),$$

and $$AL = b' = \frac{rs}{r - s}\left(\frac{b}{r} - h\right) \ldots\ldots\ldots\ldots (8),$$

where $\left(\frac{b}{r} - h\right)$ represents the height of the earthwork GD.

The horizontal distance $FQ = rh$..(9)

It is evident that the above formula can be applied to cases in which the slope of the earthwork and of the natural surface of the ground is different on the two sides of the centre line, as well as to those in which they are the same. The distances AC and BC must be known to the person who actually lays out the work, while BN and AL are necessary for the calculation of its volume.

19. **Section areas** —From the same data as are required to compute the breadths of the slopes, we may calculate the area of the cross section. Using the same letters as before, and supposing S in each case to denote the area required :—

When the ground is level across, as in *Fig.* 1—

$$S = FC.\,GB = h\,(2b + b') = 2bh + sh^2, \quad\text{.....................(10).}$$

When the ground has a uniform side-long slope not intersecting the base, as in *Fig.* 2 —

S = area of trapezoid GDEH + triangle BHE + triangle AGD.

$$= DE \times FC + \frac{BN \times HE}{2} + \frac{AL \times GD}{2} \text{ then from formulae 4 and 6.}$$

$$\therefore S = 2bh + \frac{rs}{2(r-s)}\left(h + \frac{b}{r}\right)^2 + \frac{rs}{2\,(r+s)}\left(h - \frac{b}{r}\right)^2$$

or

$$= \frac{sb^2 + 2r^2\,bh + r^2\,sh^2}{r^2 - s^2} \quad\text{..................................(11)}$$

The same quantity may also be expressed in the following manner considering its area as the difference of the triangles ABK, DEK.

$$S = \frac{r^2 s}{r^2 - s^2}\left(h + \frac{b}{s}\right)^2 - \frac{b^2}{s}, \quad\text{..................(12)}$$

This is a convenient formula for use in connection with a table of squares.

When the ground intersects the base, as in *Fig.* 3—

Here the cross section consists of two similar triangles, QBE and QAD, one in cutting, the other in embankment. Then QBE will be greater or less than QAD, according as Q is to the left or right of C, the centre point. When Q, C, and F coincide, the triangles are equal, and the excavation is equal to the embankment. Let the area of QBE, the greater of the two. as in the present case, $= S'$; the area of QAD, the less $= S''$.

$$\text{Then } S' = \frac{(BP + FQ)\,EH}{2} = \frac{(b + rh)^2}{2\,(r - s)} \quad\text{..................(13)}$$

$$S'' = \frac{(AM - FQ)\,DG}{2} = \frac{(b - rh)^2}{2\,(r - s)} \quad\text{..................(14).}$$

20. **Volumes.**—With the data obtained in the last two paragraphs, we have to calculate the volumes or quantities of earthwork in any given excavation or embankment.

Let l=length of the portion of earthwork of which the volume V is required.

I. When two cross sections S_1 and S_2 are given, and the length between them, and when S_1 and S_2 are very nearly equal, *but not otherwise*—

$$V = \frac{S_1 + S_2}{2} \times l, \quad \ldots\ldots (15).$$

II. When three equidistant cross sections S_1, S_2, S_3, are given, and whole length, then—

$$V = \frac{S_1 + 4S_2 + S_3}{6} \times l, \quad \ldots\ldots (16).$$

III. When the length l and two cross sections S_1 and S_3 only are given, the area of an assumed cross section S_2 may be found approximately, by considering the central depth as a mean between the two end-depths $\left(\frac{h + h''}{2} = h'\right)$ and the side-long slope of the ground as a *harmonic* mean between the two end slopes $\left(\frac{2rr''}{r + r''} = r'\right)$ Equation (16) may then be used; and the result will be found to be closer than what could be obtained from equation (15).

IV. When the ground is level across, this last process gives the following result; h and h'' being the depths at the two ends—

$$V = l\left\{b(h + h'') + s\frac{h^2 + hh' + h''^2}{3}\right\} \quad \ldots\ldots (17),$$

$$\text{or } V = l\left\{b(h + h'') + s\left[\frac{(h + h'')^2}{4} + \frac{(h - h'')^2}{12}\right]\right\} \ldots\ldots (18).$$

A formula convenient for use in connection with a table of squares.

V. When an *even* number (m) of equidistant cross sections S_1,S_2,S_3, S_4,…… ……S_m, are given, and d the distance between each, then—

$$V = d\left(\frac{S_1}{2} + S_2 + S_3 + S_4 + \ldots\ldots + \frac{S_m}{2}\right) \ldots\ldots (19).$$

VI. Lastly, when an *odd* number (n) of equidistant cross sections S_1, S_2, S_3,……,S_n, are given, and d the distance between each, then—

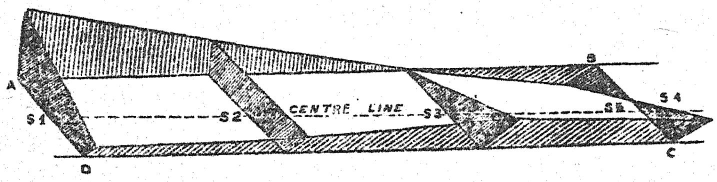
$$V = \frac{d}{3}(S_1 + 4S_2 + 2S_3 + 4S_4 + \ldots 2S_{n-2} + 4S_{n-1} + S_n), \quad \ldots (20).$$

The term "Prismoidal formula" is applied to both the equations (16) and (17), which alone are strictly accurate. If an Engineer required to obtain approximately and quickly the quantities of cutting and embankment in alternative lines or sections of a road or canal, he might advantageously use equations (19) or (20); but it must be remembered that they are but approximations, and in the case of constantly shifting gradients, or naturally uneven ground, might give very inaccurate results.

21. The following example will serve to show how the above formulae are applied :—

Let ABCD (*Fig.* 4) be a piece of road on which the sections S_1, S_2,

Fig. 4.



etc., are at equal distances of 500 feet each. From S_1, to S_3, the road is entirely in digging, beyond that point it is partly in embankment; S_5 representing a section of the embanked portion at the line BC; at S_2 the ground is level across; at all the other sections it is side-long. Let b, th. half-breadth, be 20 feet, and s, the slope of the earthwork, be 1 to 1 throughout.

Let the central depths at S_1, S_2, S_3, and S_4 be 10, 6, 2, and 1 foot, respectively, and the natural slope of the side-long ground at S_1, S_3 and S_4 be 70 to 1, 10 to 1, and 7 to 1, respectively.

I. Then at S_1 the horizontal half-breadths of the side-slopes are (equations 4 and 5),

$$b' = \frac{70}{69}\left(10 + \frac{20}{70}\right) = 10{\cdot}43 \text{ feet on the side A,}$$

$$\text{and } b' = \frac{70}{71}\left(10 - \frac{20}{70}\right) = 9{\cdot}6 \text{ feet nearly on the side D,}$$

and the area S_1 (equation 11)

$$= \frac{(1 \times 400) + (2 \times 4900 \times 20 \times 10) + (4900 \times 1 \times 10)}{4900 - 1}$$

$$= 500 \text{ square feet nearly;}$$

(or by equation 12)

$$S_1 = \frac{4900 \times 1}{4900 - 1}\left(10 + \frac{20}{1}\right)^2 - \frac{400}{1} = 500 \text{ square feet, nearly.}$$

At S_2 we have (equation 1).

$b' = 6$, the horizontal half-breadth of the side slopes, and (equation 10) $S_2 = (2 \times 20 \times 6) + (1 \times 36) = 276$ square feet.

At S_3, in like manner, we have (equations 4, 6 and 11).

$b' = 4{\cdot}4$ feet on the upper side, and $b' = 0$ on the lower side. And $S_3 = 88{\cdot}8$ square feet.

For the two sections on the line BC we have for the half-breadth of the excavated slope (equation 4) $b' = 4{\cdot}5$ feet, and the half-breadth of the embanked slope (equation 8) $b = 2{\cdot}2$ feet nearly.

Also (equation 13) $S_4 = \frac{(20+7)^2}{2\times 6} = 60\cdot 75$ square feet.

And (equation 14) $S_5 = \frac{(20-7)^2}{2\times 6} = 14\cdot 08$ square feet.

22. II. Having calculated the areas of the cross sections S_1, S_2, S_3, S_4 and S_5, we may find the whole quantities of earthwork.

To find the volume of the excavation from S_1 to S_3, the true content will be (equation 16).

$$V = \frac{500 + 4 + 276 + 88\cdot 8}{6} \times 1000 = 282{,}148 \text{ cubic feet.}$$

If we calculate the same value by (equation 15) taking the sum of the volumes from S_1 to S_2, and from S_2 to S_3, we should have—

$V = \frac{500 + 276}{2} \times 500 + \frac{276 + 88\cdot 8}{2} \times 500 = 285{,}222$ cubic feet, an error in excess of above 3,000 cubic feet. Or, if we had only the two sections S_1 and S_3 given us, and we wished to find the volume by assuming S_2 by the method shown in III, para. 16, we should have $h_1 = \frac{h + h'}{2} = 6$ feet which is correct, and $r'' = \frac{2\,r\,(-r')}{r + (-r'')} = -\frac{2\,rr''}{r - r''} = -25$.

The negative sign being here used as one slope is directly in the opposite direction to the other; and the mean slope going with that which is steepest, that is, with the one in which r is less. From the above data we should find (equation 11) $S_2 = 276\cdot 5$ square feet. only half a square foot greater than the real area, and from this calculation we should have—

$V = 282481\cdot 3$ cubic feet, an error in excess of only $333\cdot 3$ cubic feet.

In measuring the ground between S_3 and the line BC, we must take it in two portions, as it is partly in embankment and partly in excavation.

The embanked portion is merely a triangular pyramid, having for its base S_5, and its height the distance between S_3 and $S_5 = 500$ feet; its content therefore will be $\frac{500}{3} \times S_5 = \frac{500}{3} \times 14\cdot 08 = 2{,}347$ cubic feet.

The excavated portion, which is a prismoid, may be found in several ways, of which the most accurate would be to assume an intermediate section in the manner shown above.

The volume of excavation thus obtained would be $31\cdot 749$ cubic feet.

Equation 15 could not with any accuracy be applied for finding this volume, as the cross sections S_3 and S_4 differ so largely. it would give an error in excess of more than 5,000 cubic feet. Nor would it give an accurate result to find the whole volume from S_1 to S_4 by equation 19, and then to deduct the portion S_1 to S_2 already found. For that formula is only applicable to a single prismoid, such as the volume is from S_1 to S_3 and the whole volume from S_1 to S_4 is made up of two distinct prismoids. From S_1 to S_3 there is one common half-breadth of 20 feet,

but from S_3 to S_4 this half-breadth keeps diminishing from 20 to 13·5 feet, as may be found by calculation. So that the figures are in no way similar to each other.

To facilitate calculation of earthwork, many books of tables have been published, such as Sir John Macneill's, Bidder's, Bashforth's, and others, generally depending on some one or other of the formulae given in this chapter.

23. The following method of estimating earthwork originated with Colonel A. M. Brandreth, R.E. late Principal of the College, and will be found invaluable. It supersedes the complicated calculations for earthwork estimates which have hitherto been in use, whilst the results obtained are practically as accurate.

Let D and D′ represent the depths of cutting or height of embankment at both ends of the section.

l, the length of section.

s to l, the ratio of the side-slopes.

B, the breadth of cutting or embankment.

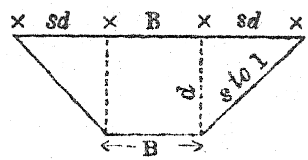
S, the area.

V, the volume.

then $S = Bd + sd^2$.

$V = l\,(Bd + sd^2)$.

Fig. 5.



24. As the formulae convey no idea of their simplicity, a specimen form of an estimate for the short section of a road, with the contents calculated out, is given below:—

1	2	3	4	5	6	7	8		9
No. of station.	Depth at station D	Mean depth. d	Area of centre portion Bd	Area of side-slopes, sd^2	Total area. $Bd + sd^2$	Distance between stations. l	*Contents* = *area* × l. Cutting.	 Em-bank-ment.	Remarks.
38	3·7	..	..	..	..	100	..	..	B = 30, s=2
39	2·8	3·3	99	22	121	..	..	12,100	
40	2·9	2·9	87	17	104	..	..	10,400	
41	—2·2	1·5	45	5	50	57	..	2,850	
		—1·1	33	2	85	43	1,505	..	
42	—2·8	—2·5	75	13	88	100	8,800	..	
43	—4·3	—3·6	108	26	134	..	13,400	..	
44	—0·2	—2·3	69	11	80	..	8,000	..	
45	2·7	—0·1	3	0	3	25	75	..	
		1·4	42	4	46	75	..	3,450	
46	3·2	3·0	90	18	108	100	..	10,800	
					Carry forward ..		31,780	39,600	

The columns are here numbered from left to right for convenience of reference.

BIDDER'S EARTHWORK TABLES,

ADAPTED FOR THE USE OF THE PUBLIC WORKS DEPARTMENT IN INDIA.

BY F. L. O'CALLAGHAN, C.E.

EXPLANATION.

The *black* figures represent the content in cubic feet of any trapezoidal solid whose length is 100 feet, width 1 foot, and whose depths at the ends are indicated by the numbers of the intersecting columns; and are intended to be applied to the central part of any cutting exclusive of the slopes. The *red* figures show the contents of 1 to 1 slopes whose heights are shown as before.

To find the contents of any cutting or embankment by the Tables:

First, find the greatest height in the bottom line and the less height in the left hand vertical column, and refer to the intersection of the vertical and horizontal columns.

Multiply the black figures there found by the width of the base of the cutting, and the red figures by the ratio of the slopes, and the sum of the products will be the contents required.

EXAMPLE.

To find the contents of a cutting whose longitudinal section is represented by *Fig.* 1 and cross section by *Fig.* 2.

At the intersection of the columns 14 and 0 are 700 and 6533, which insert in the columns *a* and *b* of the following scheme; at the intersection of the columns 14 and 17 we have 1550 and 24100, which insert as before, and so on to the end. Then multiply the sum of the numbers in *a* by 30, the width of base, and the sum of the quantities in *b* by 1½, the ratio of the slopes, and the sum of those products will be the required contents.

Fig. 1.

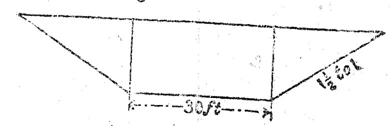
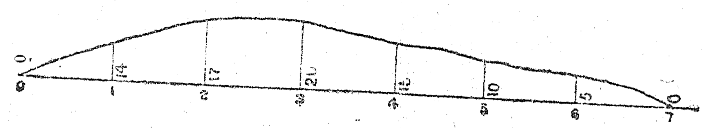


Fig. 2.



Heights.	a.	b.
0 / 14	700	6533
14 / 17	1550	24100
17 / 20	1850	34300
20 / 15	1750	30833
15 / 10	1750	30833
10 / 5	750	5833
5 / 0	250	833
Total,	8100	118265

$8100 \times 30 = 243000$ = content of centre.
$118265 \times 1\frac{1}{2} = 177397$ = „ slopes.
420397 = total content.

The Slope Table is used for finding the areas of slopes, the figures in column R being the ratio of the slope.

To find the area of the slopes of a cutting or embankment, multiply the total of column *a* by the tabular number (N) corresponding to the slope ratio, and double the product will be the area of both slopes.

EXAMPLE.

$10000 \times 1{\cdot}8 \times 2 = 36000$ required area.

SLOPE TABLE

R.	N.
¼	1·03
½	1·10
¾	1·25
1	1·41
1½	1·80
2	2·23
2½	2·70
3	3·16
3½	3·64
4	4·12
4½	4·61
5	5·09
6	6·08

	20·0	19·0	18·0	17·0	16·0	15·0	14·0	13·0	12·0	11·0	10·0	9·0	8·0	7·0	6·0	5·0	4·0	3·0	2·0	1·0
20·0	2000 / 40000																			
19·0	1950 / 38033	1900 / 36100																		
18·0	1900 / 36133	1850 / 34233	1800 / 32400																	
17·0	1850 / 34300	1800 / 32483	1750 / 30633	1700 / 28900																
16·0	1800 / 32533	1750 / 30700	1700 / 28933	1650 / 27233	1600 / 25600															
15·0	1750 / 30833	1700 / 29033	1650 / 27300	1600 / 25633	1550 / 24033	1500 / 22500														
14·0	1700 / 29200	1650 / 27433	1600 / 25733	1550 / 24100	1500 / 22533	1450 / 21033	1400 / 19600													
13·0	1650 / 27633	1600 / 25900	1550 / 24233	1500 / 22633	1450 / 21100	1400 / 19633	1350 / 18233	1300 / 16900												
12·0	1600 / 26133	1550 / 24433	1500 / 22800	1450 / 21233	1400 / 19733	1350 / 18300	1300 / 16933	1250 / 15633	1200 / 14400											
11·0	1550 / 24700	1500 / 23033	1450 / 21433	1400 / 19900	1350 / 18433	1300 / 17033	1250 / 15700	1200 / 14433	1150 / 13233	1100 / 12100										
10·0	1500 / 23333	1450 / 21700	1400 / 20133	1350 / 18633	1300 / 17200	1250 / 15833	1200 / 14533	1150 / 13300	1100 / 12133	1050 / 11033	1000 / 10000									
9·0	1450 / 22033	1400 / 20433	1350 / 18900	1300 / 17433	1250 / 16033	1200 / 14700	1150 / 13433	1100 / 12233	1050 / 11100	1000 / 10033	950 / 9033	900 / 8100								
8·0	1400 / 20800	1350 / 19233	1300 / 17733	1250 / 16300	1200 / 14933	1150 / 13633	1100 / 12400	1050 / 11233	1000 / 10133	950 / 9100	900 / 8133	850 / 7233	800 / 6400							
7·0	1350 / 19633	1300 / 18100	1250 / 16633	1200 / 15233	1150 / 13900	1100 / 12633	1050 / 11433	1000 / 10300	950 / 9233	900 / 8233	850 / 7300	800 / 6433	750 / 5633	700 / 4900						
6·0	1300 / 18533	1250 / 17033	1200 / 15600	1150 / 14233	1100 / 12933	1050 / 11700	1000 / 10533	950 / 9433	900 / 8400	850 / 7433	800 / 6533	750 / 5700	700 / 4933	650 / 4233	600 / 3600					
5·0	1250 / 17500	1200 / 16033	1150 / 14633	1100 / 13300	1050 / 12033	1000 / 10833	950 / 9700	900 / 8633	850 / 7633	800 / 6700	750 / 5833	700 / 5033	650 / 4300	600 / 3633	550 / 3033	500 / 2500				
4·0	1200 / 16533	1150 / 15100	1100 / 13733	1050 / 12433	1000 / 11200	950 / 10033	900 / 8933	850 / 7900	800 / 6933	750 / 6033	700 / 5200	650 / 4433	600 / 3733	550 / 3100	500 / 2533	450 / 2033	400 / 1600			
3·0	1150 / 15633	1100 / 14233	1050 / 12900	1000 / 11633	950 / 10433	900 / 9300	850 / 8233	800 / 7233	750 / 6300	700 / 5433	650 / 4633	600 / 3900	550 / 3233	500 / 2633	450 / 2100	400 / 1633	350 / 1233	300 / 900		
2·0	1100 / 14800	1050 / 13433	1000 / 12133	950 / 10900	900 / 9733	850 / 8633	800 / 7600	750 / 6633	700 / 5733	650 / 4900	600 / 4133	550 / 3433	500 / 2800	450 / 2233	400 / 1733	350 / 1300	300 / 933	250 / 633	200 / 400	
1·0	1050 / 14033	1000 / 12700	950 / 11433	900 / 10233	850 / 1900	800 / 8033	750 / 7033	700 / 6100	650 / 5233	600 / 4433	550 / 3700	500 / 3033	450 / 2433	400 / 1900	350 / 1433	300 / 1033	250 / 700	200 / 433	150 / 233	100 / 100
0	1000 / 13333	950 / 12033	900 / 10800	850 / 9633	800 / 8533	750 / 7500	700 / 6533	650 / 5633	600 / 4800	550 / 4033	500 / 3333	450 / 2700	400 / 2133	350 / 1633	300 / 1200	250 / 833	200 / 533	150 / 300	100 / 133	50 / 33

(*N.B.*—The full Table up to 60 may be had from the College Boo . Depôt, price Re. 0-8-0, or mounted on cloth to fold up, Re. 1-8-0).

The figures in no. 1 column are taken from the field-book, the stations being numbered so that this number, multiplied by the length of section between stations indicates the position at the end of that section on the alignment, reckoning from the starting point. Thus, if 100 feet has been used as the distance between stations, we know that the end of no. 40 station is 4,000 feet from the starting point.

The figures in no. 2 column are also taken from the field-book to the first place of decimals only. In actual practice earthwork cannot be done with greater accuracy than to the tenth of a foot, as it is useless to work out calculations further than to one place of decimals. The plotted longitudinal section of levels will show the portions in cutting; these are preceded by a *minus* sign in this column.

Column no. 3 is next filled in from column 2 to the nearest tenth Thus, for station 40, we have $\frac{2\cdot8+2\cdot9}{2}$, or $2\cdot9$ mean depth. Section no. 41 is partly in embankment and partly in cutting. The mean depth of the embankment will be $\frac{2\cdot9}{2}$, entered as $1\cdot5$ and its length will be found from the plotted section. The depth of the part in cutting is $\frac{-2\cdot2}{2}$ or $-1\cdot1$, the negative sign being prefixed as in the preceding column, to show that it is in cutting; and its length will be found from the plotted section.

Column no. 4 is filled in on completion of the preceding one, by multiplying the mean depth in each case by the breadth of road, which is a constant quantity.

Column 5 can be readily filled in with the aid of the "Table of Areas" given in the Estimating Manual, reference being made to column 3 in each case for the mean depth.

Column 6 is made up of the sum of columns 4 and 5.

Column 7 gives the length of each section. Where uneven figures are given, they refer to the sections that are partly in cutting and partly in embankment; and the sum of the two will be equal to the length of the full section.

Column 8 is the product of columns 6 and 7.

25. On comparing the results obtained by this method with those got by the prismoidal formulae, the quantities vary by about 1 to 2 per cent.

Since earthwork rates are cheap for all ordinary works this simple method is adopted.

Payments should never be made according to quantities recorded in the estimate, but on the results obtained from detailed measurements taken on the spot of the actual work done.

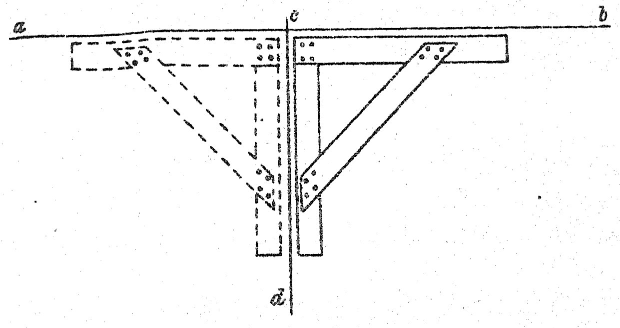
26. The proper execution of earthwork is so intimately bound up with estimating, that a few words of caution to the inexperienced may not be out of place. The supervision of earthwork is by no means so simple as it may appear. There is no class of work over which misunderstandings are so liable to arise as over earthwork measurements either between the Engineer and contractor or between the contractor and his work people, such disputes often leading to litigation. It is not therefore enough for the Engineer to insist on 'bench-marks' or 'matams' being left in every excavation as a guide for measurement; his cares commence before the first sod is turned. He should personally fix the sites for all excavations even 'bench-marks', when possible.

27. **Setting out.**—In all cases whether contractors are employed or not, the Engineer is expected to set out his own work upon the ground for execution; so that the responsibility of its form or shape rests upon himself This setting out is performed by driving stakes at the corners or angles, and straining a line or cord from one stake to the other, to obtain right lines, which are afterwards marked by pegs or small stakes driven close to the line, before it is taken up to set out another length. Or, which is much better, the line may be marked either throughout its own length, or at regular intervals by "nicking out," or by what in India is called making a *daghbel*, which consists in notching the ground along the line by means of *phaora* to a depth depending on the nature of the soil, the notch being less easily obliterated in hard than in soft soil.

When a square or right-angle has to be set out on the gound, as in digging the foundations for square buildings, or for forming square ponds or reservoirs, it may be done by the surveyor's cross or by a theodolite, first directed to a picket-staff placed in the direction of one line or side, and then on turning the instrument a quarter round or 90°, the position of a second staff will be obtained; and the vertex of the angle will be at that point indicated by a plummet let fall from the centre of the instrument. The most usual method, however, of setting out right-angles on the ground is by an instrument usually possessed by workmen, called a *ground square*. It consists of two straight-edged strips of board about 5 or 6 feet long. The ends are so united as to form a right-angle (as in Fig. 6), and are held in position by another similar strip nailed diagonally upon the other two. To use such a square for setting out a right angle, strain a line *ab* in the direction of one of the required sides. Fix the

point where the right-angle is to occur in that line, by driving a stake as at *c*, and fix another line to it. Then apply one side of the square

Fig. 6.



close to, or parallel to the first line, letting the point of the square coincide with the stake; strain the other line close to the other side of the square, and fix its end to a stake *d*; then reverse the instrument, as shown by dotted lines, and if the lines coincide, the square may be removed, and the right-angle indicated may be marked on the ground If otherwise, divide the angle formed by the two lines, and the line so dividing it will be the perpendicular required. If a number of other angles, differing from right-angles, have to be set out for short distances, similar implements to that described may be made for the purpose. In general, however, all angles that differ from right-angles are set out by the theodolite. Perpendiculars to any given line may also be set out on the ground by the same methods as they can be drawn on paper, using a measuring chain, tape, or knotted cord in the place of compasses. An approximate right-angle can always be obtained with the ordinary measuring tape, by making with it a triangle whose sides measure 3, 4 and 5 feet respectively, or any multiple of those numbers.

28. The first operation in any work in earth is to "set out" or mark the centre line and edges of the work. For a canal, railway, or road, the centre line is laid down by surveying instruments, and pegs are driven at intervals, varying with the nature and importance of work but 100 feet is an ordinary distance. A cord is stretched along these pegs, and a *daghbel*, or line, is nicked out with spade or *phaora* to mark the line. The depth to be dug below each peg is ascertained by the level, and recorded in the measurement book against the peg's number. The next operation in any work in earth is to set out or mark the edges of the work.

The pegs for the centre line should be at least 10 inches long and 2 inches square and indelibly marked. On most works figures are usually marked by paint, though this does not last as well as punching. To punch the figures two small steel chisels may be used, one with an half inch cutting edge and the other with a blunt point. Taking the parts of the figures, the integers are represented from the different parts of it as follows :—

1	2	3
4	5	6
7	8	9

┘ represents 1, ⊔=2, ∟=3, ⊐=4, □=5, ⊏=6, ┐=7, ⊓=8, ∟=9, ·=0 (a dot standing for cipher). A dot should always be put over the number to indicate the way it is to be read. Thus 146 would be ┘ ⊐̇ ⊏ ; but if read upsidedown it would represent 469, hence the necessity for the dot is apparent. Having the key to these symbols the figures can always be deciphered. A saw mark should be made 3 inches from the top of this peg. The peg should be driven into the ground as far as the mark. On this 3 inches the peg number should be marked, and in preparing the estimate the ground surface should always be 3 inches below the peg level. The small pegs generally used are often lost or knocked out of place, which causes much inconvenience.

29. In the excavation, the peg itself is not dug away, but left with the pillar of earth underneath it in the cutting, and serves as a reference for measuring the depth of the excavation without putting one to the necessity of again using the level.

On many works it is advisable to have separate bench-mark pegs or masonry pillars or stones fixed 3 to 5 feet outside the work to mark the correct lines and levels and their positions, should be recorded in the measurement and level books. It would be very difficult to keep intact all the necessary bench-marks in a large canal which runs through uneven country, and in high embankments it is impossible to maintain the pegs. In all such cases it is advisable to transfer the line outside and on one side of the work. Careful preliminary operations will save much time and trouble later on, and will greatly assist in the correct execution of the work. Cuttings or embankments are liable to get out of line. If the pegs are lost the slopes are wrongly cut or carried up, correct measurements are made difficult, and later on considerable expenditure may have to be incurred in rectifying the mistakes.

For such reasons I repeat—

(1) Prepare longitudinal and numerous cross sections before the work starts.

(2) Line out clearly both the centre line and side lines, and all places where the earth has to be excavated for the embankments, and where the original surface of the ground is not to be touched.

(3) Use an ample number of strong bench-mark pegs. Whenever these cannot be left intact till the completion of the work, fix subsidiary pegs outside the work to enable the portion under construction to be checked and kept according to orders without difficulty.

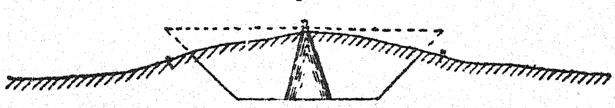
(4) All pegs should be neatly marked with paint or in some other way to enable them to be read easily and at any time.

(5) Numerous and good profiles should be made and continually checked, as these can easily be tampered with by contractors.

30. **To set out side widths.**—The formulae given above for finding the side widths of any embankment or cutting, though useful in office calculations, are not generally applicable when actually setting out either a railway or canal, for the two following reasons—1st, the ground is seldom found to fall with so regular a slope as to allow the formula to be used, since the least deviation from the slope that has been assumed (such, as a hillock or mound) will throw the widths out; 2ndly, that as *cross sections* at each chain stump must be taken in order to find the slope (r in the formula), it is easier to plot the section and take the side widths off by scale, than to investigate them mathematically.

31. It is evident that although the central line of stakes by which a road or canal has been set out must be regular, this can never be the case with the exterior, or side bank stakes, which must always stand in irregular or zigzag lines unless they are on perfectly level ground; notwithstanding which, the work set out by them will be straight and regular when finished, and brought to one uniform height. Certain conical masses with grass and stakes on their tops, termed bench-marks* by the Engineer, and *matams* by the natives of these provinces, are generally found standing in the middle of canals, reservoirs and other excavations, particularly in uneven countries in form like y in the figure.

Fig. 7.



* Not to be confounded with the bench-marks used in levelling.

Their use is to mark what was the surface of the ground before it was touched; for they are not built up, but consist of some of the former soil left standing by digging the earth away around them. The grass growing upon them is the grass of the original surface which having been untouched, continues to grow and prevents any deception being practised as to the actual former height of the soil, when the quantity of excavation is measured after its completion. It is important that the Engineer should satisfy himself by inspecting the tops of these bench-marks, and by the general lie of the ground that no deception has been attemped. A mode of deception sometimes practised with these bench-marks is to carefully remove the top, add a few inches to the pillar, and then replace the grass top, dressing the sides to make them appear as natural soil. The workmen if left to themselves will invariably select the highest place for the bench-mark or *matams*; so, if the cross section of the ground is not level or on a regular slope, it is advisable to leave a thin wall right across the cutting at regular intervals, or at places which have been selected by the Engineer.

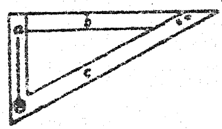
These little hillocks likewise serve to preserve the positions of the central line of stakes by which the work has been set out, for they are usually left round those stakes or round every second or third, as may be necessary, so as to give the Engineer an opportunity of levelling at any future time from the original centre stakes, or measuring distances from them to the side banks, or taking the depth of the cutting. And they are never removed until the work has been measured or in such a state of forwardness as to render their longer retention useless.

It some times happens that the cutting or excavation for a road or canal is very deep and wide at the top, as when a hill has to be passed through; and in that case these bench-marks cannot be left, for the base would of necessity be so large as to block up the lower part of the work, in such places the surface of the ground can only be determined by carefully levelling it previous to beginning the excavation. For if any hollow or protuberance in the natural ground exists, either on a hill or any other place that has to be cut through, it may make a considerable addition, or abstraction from, the quantity of earth to be removed, and it is frequently a source of dispute with workmen.

32. When the extreme sides or lines of a portion of earthwork have been set out, nothing more is necessary in order to produce the figure or form required than to desire the workmen to proceed and excavate up or down the slopes with an inclination that may have been previously arranged; but it may not be obvious how the necessary correctness of slope is to be obtained and preserved. This is done mechanically, either by means of an implement called a bevil plumb rule or by a clinometer.

The bevil plumb rule shown in *Fig.* 8 consists of three strips of board *a*, *b*, and *c*, framed together in the form of a triangle, the piece *a* being a common plumb rule and plummet, such as is used by bricklayers, and which being held upright, the piece *c* is so fixed as to represent the slope required for the bank, and *b* is merely a brace for retaining

Fig. 8.

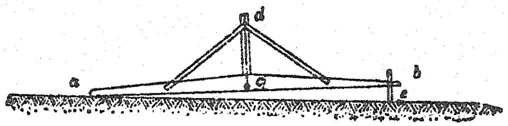


the other two pieces in their proper angular position, and therefore need not make a right-angle with *a*, though it will be better that it should do so, because the implement then becomes useful for other purposes. This sloping side *c* ought to be at least 3 feet long; and separate instruments of this description will be necessary for each particular slope, if more than one slope should be adopted. Having such an instrument, there will be no difficulty in giving the necessary slope to the banks. Thus, in *Fig.* 1, suppose A to be the exterior stake at which the slope is to terminate. The workman begins by opening a hole of about a foot or 18 inches wide between A and G, taking care to give sufficient slope to the side AD; when deep enough, say a foot or two, the lower point of the bevil plumb rule is introduced into this hole; and its side *c* is brought into contact with the slope AD; and then, if the plummet on the rule coincides with the line upon it, the slope is right; if not, it must be altered until this accordance takes place. That done, another similar hole is opened at the next outer stake a few yards in advance, and is proved and adjusted in like manner, when the intermediate earth may be bodly taken away, until the excavation approaches very closely to the lines so set out. When that is the case, more care and caution are required to pare away the earth in exact accordance with the lines which have been laid out, and the bevil rule is frequently applied to ascertain that the work is correct. By the same process the slopes are set out and adjusted on the other side and throughout the length of the work.

33. Although by the bevil plumb rule and clinometer earthwork may be executed of any required cross section, some other means must be taken to guide the workmen in forming the longitudinal section of a work, such

as a road, where the slope will rarely exceed 1 in 30, and will generally be much less. For a bevil rule, where *b* (*Fig.* 8) is 50 times *a*, would

Fig. 9.



require to be of a most unwieldy size to be of any use. For this purpose a large Mason's Level may be used as shown in *Fig.* 9. The beam *ab* is placed truly horizontal by raising or depressing one end till the plumb bob suspended from *d* falls exactly on *c*. So if a slope of 1 in 60 is required, and *ab* be 5 feet long, *be* will be fixed at one inch (1-60th of 5 feet); and pegs driven flush with *a* and *e* will so far determine the slope of the road. The level may then be carried on, and *a* placed over the peg which was driven at *e* and so on for 20 or 30 feet, and then a string drawn tightly over those pegs and produced will give the slope for any length in advance.

34. Another method of laying down a level surface or a longitudinal slope is by the use of boning staves. This is the simplest and most accurate method, but subordinates and contractors will never use boning staves if they can help it.

Boning staves are upright rods of one length having cross-bars at right-angles to their tops in a T shape. By means of a levelling instrument two pegs are driven in the centre line at about 50 feet apart with their heads exactly in the required slope. On these pegs two boning staves are placed with their cross-bars lying at right-angles to the centre line, and a third is held upright at any point in the cutting in the same line as the other two; when, if the level of the cutting be on the required slope, the heads of the three boning staves will be in one straight line. In this manner the cutting may be carried on at a uniform rate of inclination; but whether a mason's level or boning stave be used, pegs ought to be driven at frequent intervals along the centre line, with their heads ranged exactly in the slope by a levelling instrument to check the work, otherwise there is very apt to be an error made.

35. It is usual to mark out the bottom width of the cutting on the ground surface by lines parallel to the centre line; as often the centre piece is taken out first and the slope struck afterwards.

36. The edges of the slopes must next be marked. The breadth or distance from the bottom width will, evidently, vary with the depth of the

excavation, being s times the depth, according to the slope decided on, s to l. These breadths will be set out at the pegs, and lines run from point to point to mark the top of the slope, see *Fig.* 10.

Fig. 10.

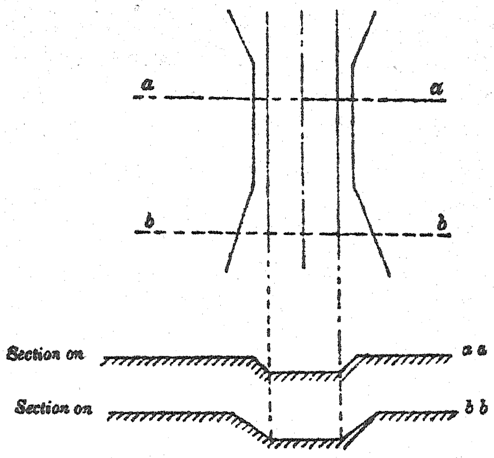


Fig. 11

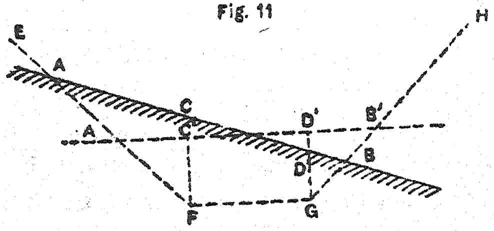
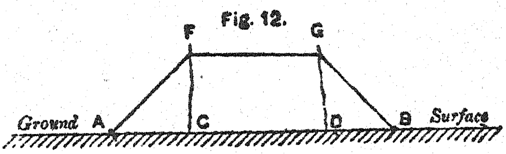


Fig. 12.



37. If the ground slopes across the line of canal, the breadths of the slopes will be more on the higher and less on the lower side than on flat ground, see *Fig.* 11. AC is more than A' C' and B D less than B' D', but the cross slope is seldom sufficient to make this worth taking into account in the plains of India. In a hill road it would of course always need to be considered. There are various ways of finding the correct width. The simplest is probably to have the work section drawn to a good large scale, with a depth greater than any required, as shown by the dotted lines

E, F, G, H, *Fig.* 11, and then to plot the line of the cross section of the ground at the spot on it, at its true height above the canal bed as AB, and measure the distances AC, BD on this line at which the banks of the section cut it. This really takes less survey than the usual method by trial, and is quite accurate enough.*

38. If the work be a bank instead of a channel, the setting out is precisely similar, centre line, top widths, and foot of slopes, but profiles must always be constructed as in *Fig.* 12 either at each or at occasional pegs. These are made by setting up poles at the breadth of the top of the bank apart, as CD, and marking the correct height on them, and then fastening a stout string from the pegs marking the side widths, as AFGB. The earth then has to be piled up to the string.

String profiles are very liable to be blown down or altered, so earthen profiles, 5′ to 10′ in width are frequently made. All profiles, however, whether made of string or earth, must be frequently checked, or they will certainly be tampered with.

39. Sometimes the excavated earth from a cutting is utilized in making banks that are part of the same work; but if there is more than is wanted, it is called spoil, and has to be placed in some sort of neat shape, which is called a spoil bank. The space this will occupy must be calculated out and the ground marked out for it as for any other bank. Again, for a bank for which there is no corresponding excavation, pits, called borrow pits, must be calculated and marked out, adjacent to the embankment from which the necessary earth can be obtained. Intervals should be left in long spoil banks to let the natural surface drainage through, and similarly borrow pits should not be dug in one continuous length, as the rain might accumulate and make a drainage line, but separate pits, say 90 feet long, with 10 feet width untouched between, should be laid out.

The earth thrown up at irregular heights on a spoil bank gives it an unworkmanlike appearance, the spoil should be thrown up to some specified height, and all in excess should be thrown behind the bank when it reaches that height, so that your spoil bank will be of uniform height throughout, but of varying width. The height you fix upon must vary with the value of land and the average amount of spoil to be deposited. It may be worth while to give the bank a long outward slope, which the villagers would be willing to buy or rent for cultivation. The rates for lift and lead and the cost of land, should be considered before the section of the spoil bank is settled upon, as it may be more economical to make a low and wide rather than a high and narrow bank.

* See appendix.

A spoil bank or bank of any kind should never be placed on the edge of a cutting; a berm varying in width with the size of the bank and other circumstances should invariably be left between the top of the cutting and the toe of the bank above it. On the same principle, borrow pits should not be cut too close to the toe of an embankment. When a river has to be diverted, or in any other case where scour is likely to take place, it is very important to keep the spoil bank at a safe distance from the channel. Unless this is done it may happen that the scour undermines the spoil bank and the channel gets blocked. Again, when side drainage enters a cutting, unless it is properly provided for, it may happen that the spoil bank may be washed back into the channel, or the drainage may be diverted in such a way that damage may be done.

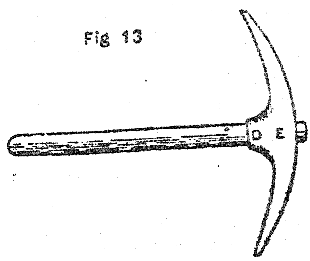
CHAPTER III.

TOOLS, EXECUTION AND RATES.

40. The tools used in India are usually the Indian spade called the *phaora*, the pickaxe, the basket and the barrow. The *phaora* is too well known to need description, but for large works it is well worth while to see that good ones are provided to the coolies. Those used by the Lunnias or professional excavators, are large and of peculiar make, and are beyond the power of an ordinary coolie to handle, but a moderately sized, sharp, well-balanced tool will repay its price. Pickaxes are only used to loosen the soil when it is very hard. In the hills the pickaxe and English shovel are chiefly used. For hard soils in the plains workmen frequently use a *kodali* in preference to a pickaxe. A *kodali* is an implement with one point only like a half pickaxe and workmen prefer it to the pickaxe on account of its lightness.

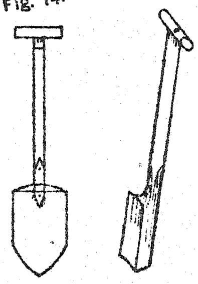
41. **Pickaxe.**—Where the soil is stiff and firm, it must be broken up by a tool more powerful than the *phaora*, and for this purpose a pickaxe is used. It is made of iron and has two points of steel welded on to it, and is bent to the form shown in the marginal figure. For ordinary excavation it should be double ended, with an equal quantity of metal in each end, so as to balance well in the hand. Two feet from point to point is considered the most convenient length, and the metal should not weigh more than 10 or 12 pounds; if heavier, it fatigues the workman without an equivalent advantage in work. One end is generally pointed, the other end is shaped like a chisel with the point about one inch wide. The common fault in pickaxes, as they are usually made, is a want of sufficient depth and strength in the socket through which the wooden handle passes, for it is in this place that they usually break. The side plates that form the socket ought not only to be thick for strength, but should be at least $3\frac{1}{2}$ or 4 inches from D to E in order to admit of the handle being well fixed; for the operation of this tool is of a wrenching character and unless this construction is attended to, the

Fig 13



handles often break or work loose. Pickaxes frequently require sharpening and repairing; hence if there is no blacksmith in the immediate vicinity of the work, a portable forge should be provided.

Fig. 14. Fig 15.

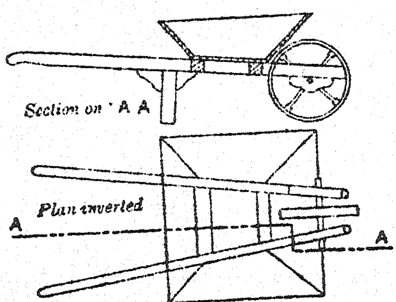


42. The shovel most approved of is heart-shaped, as shown in *Fig.* 14, instead of straight-edged, though some of both sorts are useful; they are sometimes used with a long handle, but the crooked handle, as shown in the figure, is a stronger and cheaper form. Two men are generally employed in the use of the shovel, one man to hold the handle, the other to pull a rope attached to the shovel and so assists in lifting it up.

43. Baskets can be procured in most places, but there is a great difference in their make and material. A good basket costs very little more than an inferior article and lasts double the time. In this country, when the work is not on a very large scale, and the lead not very great, it will generally be most economical to use baskets in preference to any other vehicle. The basket is the natural carrying implement of the coolie, so it requires no teaching to instruct coolies in its use. Baskets are also easily obtained everywhere, at a very small cost, whereas the price of a barrow is considerable.

44. Barrows are very seldom used in India, but when used they should be made on a proper pattern, and proportioned in size to the strength of the men about to use them. The main points of the construction are—see *Fig.* 16—a frame of two long arms with two cross pieces mortised in and secured by iron straps. The arms are at a convenient distance for a man's hands at one end, and close up at the other, so that the wheel axle is very short, and can thus be thin and run with little friction. This frame also carries the legs

Fig. 16.



pushed by men, but for engine haulage they cannot be compared with the English made trucks which are far stronger, last much longer, and cost the same amount of money.

There are several objections to work done with tilt trucks. The bank made with earth so deposited is not uniform, the layers are very thick, and clods are hidden and settlement is uneven. When the banks are made to hold up water it is advisable to lift the earth after it has been tipped and to lay it in even shallow layers by hand. As a rough guide it may be taken that when the lead necessitates a rate of more than rupees five per thousand cubic feet, tip trucks with light rails are advisable. In such cases the rate will remain much the same whether the lead is 500 feet or 1,000 feet.

The most convenient size of hand tip trucks holds 28 cubic feet of loose earth, or 20 to 25 cubic feet by borrow pit measurement, according to the kind of earth used and the size of clod into which it has been broken.

These trucks are usually carried on lines weighing 10, 14, or 18 lbs. per yard length. The 10 lb. rail is too light for most works, and gives a lot of trouble, especially if it has to be laid on made earth.

14 lb. rails do very well for hand work, but the 18 lb. rail gives the least trouble, and can also be used for light engine traffic.

In places where there is an embankment near a cutting it is often advantageous to use tip trucks, even if the earthwork rates are low, as the earth taken from the cutting can be utilized for the embankment.

When it has been decided upon to construct a work with the help of tip trucks, the greatest care should be taken to lay out the lines to the best advantage, so that the maximum number of men can be employed for the number of trucks that are available. Unless this is done before the work is started it is quite possible that deep borrow pits may interfere with the best alignment. When a bank is being constructed on a slope, as in the case of a dam or railway embankment across a river, the lines should be laid so that the full trucks can be run down hill or on to the embankment itself. Generally, however, it is necessary to run to the toe of the slope and tip there. The earth must then be lifted and carried by baskets to the top of the bank.

Contractors invariably ask for more trucks and lines than are really necessary. As a general rule one truck is required for every 10 to 15 men, but where the arrangements are good as many as 20 men can be employed on one truck. Thus a gang of 60 men will require from 3 to 6 trucks, for while one or two are being emptied by some of the men the others are being filled.

The men who fill the trucks should always be paid by borrow pit measurements. If payments are made by the truck, many more trucks are required, and they are seldom properly filled. On the other hand, it is generally best to pay by the truck for pushing, emptying and lifting the earth on to the bank.

Contractors generally pay Rs. 2-8-0 per thousand cubic feet for filling trucks, Re 1-4-0 to Re. 1-8-0 °/₀₀ for pushing emptying and lifting the earth on to the bank.

Over and above this there is the cost of mistris and mates, the breaking of clods, the cost of tools and baskets, and the final dressing of the earthwork. The contractor's total cost is therefore about Rs. 4-12-0 to Rs. 5 per thousand cubic feet, and he will generally get a contract rate from Rs. 5-8-0 to Rs. 6-8-0 °/₀₀ for such work.

41. **Locomotives for hauling trucks.**—Earth can be hauled cheaply for a distance from 1 to 2 miles by means of light locomotive engines. The Engineer must use his own judgement regarding the size of the trucks, the weight and gauge of the rails, and the horse-power of the engines which he uses.

For isolated works the carriage of the plant is an important consideration, so he naturally selects the lightest plant which is compatible with the conditions of the work. He must consider the amount of work to be done, the time available for it, the distance of the carriage, the height of the lift and the curves that are necessary.

It is useless to expect an engine to be able to run up steep banks or round sharp curves. Where there are no steep grades or curves of less than 300′ radius a 12 horse-power engine can be used, and this will haul 20 to 25 tip trucks of 28 cubic feet capacity. It is however generally more economical to use an engine with 20 horse-power, and trucks with a capacity of 36 cubic feet, as the repairs to the lines and the running expenses are nearly the same for all light engines.

The smallest size of line which can be used for engine haulage weighs 18 lbs. per yard, and this must be most carefully laid.

Wooden sleepers give a much better track than the light steel sleepers which are sold with the steel rails. Steel sleepers however keep the gauge true, so it is best to combine wooden and steel sleepers using them alternately. A good broad wooden sleeper should be placed under every joint in the rails.

Steep grades and sharp curves must be avoided, and the line must be laid carefully in the first instance, and always kept true while in use. On

the curves and grades depend the number of trucks which can be hauled, while the condition of the line regulates the speed at which the train can travel.

On the Ghori Dam in the Mirzapur district a small 12 horse-power locomotive was used, and performed an average of 16 trips a day with 20 to 25 trucks, the earth being carried about 1¼ miles.

In a working season of 180 days an average of 8,200 cubic feet of earth were carried per day.

The average daily expenses for haulage were :—

	Per day. Rs.	a.	p.
1 engine driver at Rs. 35 per mensem	1	4	0
1 stoker at Rs. 8	0	4	0
1 chaukidar at Rs. 6	0	3	0
1 line mistri at Rs. 18	0	9	0
3 men for water at 3 annas per day	0	9	0
7 men repairing line at 3 annas per day	1	5	0
2¼ seers lubricating oil for engine and trucks	1	6	0
Cylinder oil, cotton waste, red lead, asbestos, packing, spares and repairs to engine and trucks	4	0	0
125 cubic feet fuel cut from Government land	2	8	0
Total ..	12	0	0

This means that the rate per thousand cubic feet of earthwork was a little less than Re. 1-8-0 per thousand cubic feet.

On the Karamnasa cut in the same district, where two 20 horse-power engines were used, earth was hauled in 36 cubic feet capacity trucks a distance of 1½ miles at a rate of Re. 1-5-0 per thousand cubic feet.

To these rates must be added the depreciation on the line and engines. This is generally calculated at 10 per cent. per year, and would mean that from one to two rupees must be added per thousand cubic feet of earthwork. The carriage of earth up to a distance of 2 miles by means of locomotives therefore costs from Rs. 2-8-0 to Rs. 3-8-0 per thousand cubic feet.

In the above-mentioned works wood was exclusively used as fuel, as this could be bought standing from Rs. 5 to Rs. 10 per hundred maunds. In some places it was obtained free from the land already acquired, and then the only charges were for cutting and carriage.

For economical working when engines are used for haulage it is absolutely necessary to get the maximum work out of the engine, and in order to do this the following points must be attended to :—

A full load of trucks must be run in every trip, a full load being one that the locomotive can pull satisfactorily without stoppages round the curves and up the inclines. There should also be no delays at either end of the run, or in watering and in obtaining more fuel for the engine.

This means that the gangs of men who are employed at both ends of the run must be adjusted so that they can fill up a full train load of trucks at one end, and remove or level off or otherwise adjust the earth brought on to the new bank at the other end of the run in the time that the locomotive takes to do one trip.

If the engine has to wait any length of time at either end of the run it is evident that the number of trips and the outturn of the work is reduced For this reason there is often a difficulty in getting contractors to do all the work, and it frequently happens that it is best to employ certain contractors for filling the trucks and others for disposing of the earth at the end of the run.

In this case the locomotives should be worked by departmental agency.

49. **Excavation of earthwork by steam navvy.**—On the Karamnasa cut mentioned in paragraph 48 an 8 ton steam navvy was used to excavate a cutting 24 feet deep. The earth was filled into trucks of 36 cubic feet capacity, and hauled by locomotives to make up an embankment behind.

The navvy had a bucket of $1\frac{1}{4}$ cubic yards capacity, so that each cut of the navvy exactly filled a truck The navvy could make as many as 50 cuts an hour, but the machine had constantly to be moved forward and there were various other delays, so the daily average was generally about 30 cuts an hour. A hopper was found most useful, the earth from the navvy being dumped into the hopper, and from it into the trucks. This broke the fall of the earth, and so saved the trucks from injury, and as the bucket of the navvy could be emptied quickly into the wide mouthed hopper, very little earth was spilled.

It is very difficult to keep up steam with wood fuel, but it was impossible to use coal as the machine was working 70 miles from the nearest railway station.

It was also hard to get good drivers to stay so far away in a jungly place, and at times coolie lobour was very scarce. All spare parts had to be got from Calcutta and any breakdown meant great delay.

It will thus be seen that the navvy was working at a great disadvantage.

Trucks were filled with earth at the rate of Rs. 3 per thousand cubic feet exclusive of depreciation.

With depreciation on the machine at 10 per cent. per annum the rate comes to Rs. 5-6-0 per thousand cubic feet. It will therefore be seen that a Steam Navvy cannot compete with coolie labour unless the soil is very hard, labour is scarce, or there is a great quantity of work to be done.

The working expenses of one 8 ton steam navvy during March, 1915, were as follows:—

			Rs. a. p.	Rs. a. p.
Labour	1 foreman at Rs. 40 per mensem	..		40 0 0
	2 divers at Rs. 30 each ,,	..		60 0 0
	1 blacksmith at Rs. 20 ,,	..		20 0 0
	2 firemen at Rs. 11 each ,,	..		22 0 0
	21 beldars at Rs. 8 each ,,	..		168 0 0
Fuel	1,028 maunds wood	..		92 0 0
Oil and sundries	15 gallons cylinder oil ..	..	24 6 0	
	9 gallons lubricating oil ..	..	13 8 0	
	35 lbs. cotton waste ..	..	7 13 0	
	4 seers tallow ..	..	2 0 0	
	8 lbs. white lead ..	..	2 0 0	
				49 11 0
	Grand Total	..		451 11 0

For this 150,692 cubic feet were excavated, so the rate comes to Rs. 3 per thousand as mentioned above.

The total rate for the earthwork excavated by the navvy and carried back by locomotives for a distance of 1½ miles, there emptied and used on embankments was as follows:—

	Rs. a. p.	
Excavation by navvy	3 0 0	per thousand
Depreciation on navvy	2 6 0	,,
Carriage by locomotive	1 5 0	,,
Depreciation on two locomotives and two miles of line	2 2 0	,,
Contractor's rate for emptying trucks and spreading in layers on embankment	3 4 0	,,
Add for spares and repairs, etc.	1 0 0	,,
Total ..	13 1 0	

In the Punjab where larger machines were used and where they were not working at so great a disadvantage the rate was brought down to Rs. 10 per 1,000 cubic feet.

The new Bombay docks were excavated by 12 ton steam navvies which dumped into 4 cubic yard wooden tip trucks.

The lower portion of the excavation consisted either of very hard rock, parts of which had to be blasted, or of large boulders in stiff clay, many of which would not fit into the navvy bucket and had to be chained

and attached to the teeth, and so lifted out of the cutting into the trucks. The earth was loosened by large charges of dynamite exploded at some distance in front of the cutting face. The contractor's rate for the work was Rs. 20 per thousand cubic feet. The cost of labour in those parts is 8 annas per day per coolie, so the navvy was a paying machine.

50 Mechanical appliances, though certain to come more and more into use, must always be adopted with caution. The number of working days in India varies from 180 to 250, according to the locality. In wet districts like Mirzapur no earthwork can be done during the rains, holidays are numerous and during crop cutting sufficient labour cannot usually be obtained to keep the machine running efficiently. In that district 180 full working days is the maximum which can be counted on during the year.

Machines to be efficient must be kept moving, and this the Indian contractor cannot understand, so unless there is careful supervision it is a waste of money and time to use machinery unless the work cannot be completed otherwise.

51. **Work by donkeys and bullocks.**—Donkeys and bullocks are often extremely useful for the construction of high embankments. Donkeys do not however thrive everywhere and it is useless importing them to very damp places, or where fodder is scarce. When the rate for earthwork is less than Rs. 7 per thousand cubic feet it is inadvisable to try and use donkeys or bullocks.

Some 300 bullocks were employed with great success on the Ghori Dam in the Mirzapur district The contractor paid the owners Rs. 4-8-0 per thousand cubic feet where the embankment was about 25 feet high and Rs. 6 per thousand cubic feet where it was 40 feet high, he also had to provide tools and one beldar for every three bullocks. The beldar's work was to dig and loosen the earth, for the owners of the bullocks refused to do this.

Each bullock carried from 70 to 90 cubic feet of earth per diem according to the height of the bank.

Bullocks have often been used to pull trucks from place to place and it is strange that they are not more extensively used for the carriage of earthwork, as they are easily trained and are available everywhere.

52. **Rates.**—The rate for earthwork varies in different places according to :—

(1) The nature of the soil.

(2) The lead and the lift, and the kind of work to be done.

(3) The labour and the qualifications of the labour available, and the customary daily wage that is earned. The local labour varies greatly in different localities, men in one place being accustomed to doing much more work than those in another place, even though their daily wage is the same.

For small works it is seldom possible to import labour, but for large works it is generally absolutely necessary to do so, as the local labour will be insufficient to carry out the work within a reasonable time, whatever wages may be paid. Soils vary greatly in many places, and the same soil varies at different times of the year. Some soils, when they are dry or are caked, require double the exertion to loosen them that is necessary when they are damp. Low lying places may be flooded during the rainy season, the top soil may be cultivated and loose, while lower down it may be very hard.

Each site requires careful consideration, as the rate so greatly depends on the amount of earth that a man can dig in a day, and the rate of his daily wage.

In calculating the rate it is customary in India to consider the rate for a thousand cubic feet of earth dug and removed and laid according to specification, for a lead up to 100 feet, and for a lift up to 3 to 5 feet. In some places the lift is only assumed up to 3 feet, but in most large engineering works 4 feet to 5 feet is allowed. An additional rate is given for every extra lead of 100 feet, and for every extra foot of lift. The amounts paid for extra leads and lifts vary in different places, some people considering an extra lift of 3 feet as being equivalent to an extra lead of 100 feet, but in the United Provinces an extra lift of nearly 8 feet is generally considered equivalent to an extra lead of 100 feet. On the other hand, it must be remembered that the lift for very high banks requires special consideration. Many labourers will sooner run away than carry earth up high banks, and for such places it is always advisable to try and arrange for donkey or bullock carriage.

Small variations of lift are of no consequence to donkeys and bullocks, and the same remarks apply to leads when trucks and rails are used.

53. The most useful class of labourer in Upper India is the "Lunnia" who comes chiefly from Partabgarh, Jaunpur, and the surrounding districts. These men go, with their families, all over India during the winter months, and return to their homes to reap the crops and plough in the hot weather though a certain number may remain on the works throughout the year. In order to keep these men on the works the Engineer should encourage them to bring their cattle and to cultivate locally, otherwise they are apt to take advances, commence a little work,

and then disappear. They are also most ingenious in making *matams*, and are great grumblers. On the other hand, they are invaluable when there is a large amount of work to be done as they are quick and neat workers. They will never work if the soil is hard.

When the soil is soft a "Lunnia" will turn out 200 cubic feet of earthwork a day. Other good workers are "Beldars" of Gorakhpur, and the lowor castes of Ajmer and Marwar.

When there are high embankments and the earthwork must be done quickly without great care, the "Pathan" with his donkeys is the best man to employ. These men however always ask high rates, and often give a lot of trouble.

The average labourer in ordinary soils does not dig more than 75 cubic feet of earth per man per day; that is, one digger and one carrier will between them excavate a pit $12' \times 12' \times 1'$ and carry the earth to the bank, but if the soil is hard a pit $10' \times 10' \times 1'$ is as much as the two men can do between them unless they are specially trained. Earthwork rates are rapidly rising and where the initial rate used to be Rs. 2 ‰, the lowest rate at the present time in most places is Rs. 2-8-0 to 3 per thousand cubic feet. Where labour is imported the railway fares, huts and advances (which often cannot be recovered) must also be taken into account.

A very usual rate is Rs. 3 ‰ which includes a lift of 5 feet and a lead up to 100 feet Above this an extra one anna per thousand cubic feet is paid for every extra foot of lift, and eight annas for every extra 100 feet of lead. For high banks one and a half annas has generally to be given for every extra foot of lift over five feet.

When labourers have to be imported an initial rate of Rs. 3-8-0, Rs. 4 or even possibly Rs. 5 per thousand cubic feet has often to be given to cover the extra items mentioned above.

54. **Tools used in rock excavation.**– Soft rocks and thin stratified rocks are generally excavated by hand tools, pickaxes, crowbars, sledge hammers, and wedges.

Pickaxes have already been described in paragraph 41. Crowbars are steel rods, an inch or more in diameter, and 3′ to 6′ long. One end is shaped like a chisel, the other end is sometimes bent to permit of its being used as a lever. Crowbars which are merely used for boring holes are generally called jumpers.

Sledge hammers are made in several shapes, and of varying weights. They are used for breaking up quarried stone, and for driving in wedges when the purpose is to separate a mass of rock from its bed. They are also used to hammer on short crowbars or jumpers for boring holes in hard rock for blasting purposes.

Wedges are made of iron, steel, or wood. A slot is cut in the rock by a pick, chisel or crowbar, the wedge is then inserted in the slot and driven home with a sledge hammer. Large wooden wedges are sometimes used for very soft or thinly stratified rock.

There are many kinds of rock drilling machines on the market, but these are seldom used in India.

55. **Boring tools.**—Before an estimate for a deep cutting can be prepared, it is necessary to ascertain the kinds of earth or rock which will be met with. For this purpose numerous geological sections are prepared, and these can be made either by the excavation of open pits, or by boring tools.

The former method is the most expensive, but it gives a far more accurate idea of the strata through which the cutting has to be taken. Sections prepared with the help of boring tools are not to be depended upon, as the specimens brought up are crushed by the action of the boring tool, and are sometimes reduced to paste by the water which is poured into the hole to keep the tool cool.

The ordinary boring tools are the auger, the worm, and the jumper. These are made of wrought iron, steeled at the points and cutting edges. They are about 1½ foot long, welded on to an iron bar or shank of about an equal length, and 1⅛ inch square. At the top of the shank is a screw, connecting it with lengthening rods. These are square bars usually about 10 feet long, of the same diameter as the shank, with screws at their ends by which they can be joined together, to any length required. The uppermost rod is capable of being hung by a swivel and rope from a triangle or shears set over the boring hole, in order to haul up the rods.

The auger which is used for all ordinary earths, shale and soft rock is formed like a hollow cylinder, about 3½ inches in diameter, with an open sharp-edged slit along one side of it. It is slightly contracted at the lower end, and sometimes has a small special point like a gimlet for boring in soft rock. It brings up specimens of the earth in the inside of its cylinder.

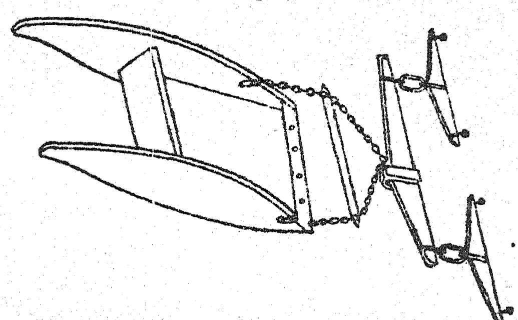
The worm is a sharp-pointed spiral, used for boring rocks too hard for the auger. After the worm has pierced the rock, the auger enlarges the hole and brings up the fragments. Both the auger and worm are worked by turning them continuously round towards the right, by means of a cross-head, about 6 feet long, driven by men.

Jumpers are used to pierce rock too hard for the worm. They are of various shapes, some flat like a chisel with a sharp edge at the lower end; some square with a four-sided point; and some spear-pointed. The jumper

is worked by raising it to a short distance, and then dropping it twisting it half a turn round after each blow. It is sometimes simply hung by a rope instead of by lengthening rods. The auger is afterwards sent down to bring up specimens. In boring through very soft ground a series of iron pipes are sometimes pushed down to keep the hole open; these may be made to screw one to the other, so that they can be hauled up again.

56. **Scoop.**—In removing surface earth to a moderate distance, an implement called a scoop, serving the purposes of the shovel and the wheel-barrow combined, is used in America, and in some parts of India. It consists of a large open box like a hand-barrow, with three sides instead of four, and the bottom projects with a sharp edge, to the front. Being dragged along by bullocks, it is made to scoop up the earth from the surface at its open end, and to convey it along. The attachment of the two chains or ropes by which it is dragged is made at about the middle of the scoop, and the scoop is provided with two handles to the rear by which it is guided. These handles are slightly raised by the hand of the driver on reaching the point where the earth is to be laid down. The front edge (which is armed with iron) catches in the ground, and the oxen moving on the scoop is overturned. It can only be used of course when the earth is tolerably soft and loose, and for this reason it is rarely used with success in India. To facilitate excavation of ground having a stiff or hardened surface, it is frequently ploughed before setting the scoop to work. Special ploughs are sometimes used to break up hard soil and save the *phaora* or pick work. They are useful, but it is difficult to train the oxen for the work.

Fig. 17.



57. Contractors should, whenever possible, be made to supply their own tools; but when the Engineer has to arrange for the supply of tools, a great deal of trouble and expenditure will be saved by using some proper system of issues.

Large contractors can always arrange for every kind of tool, except perhaps engines, pumps and tip trucks; but the work done by these men is generally more expensive than that done by numerous small men. The small contractor can only supply petty articles such as the *phaora*, shovel, pickaxe and basket, and for the first month of the work it is often best to supply a certain percentage of his requirements to enable him to get quickly to work. A supply of tools must be kept for emergencies and repairs, but otherwise the fewer tools that are supplied to contractors the better it will be, the work will be more economical and much trouble will be saved.

All new tools should be stamped with some special mark and year of issue—as, for instance, the initial letters of the road or canal on which they are being used—and no tools should be received back into store that have not this mark. They should be issued by weight or by length of blade, or by any other way found convenient; and weighed or measured on return by the store-keeper; the contractor paying for the use and loss by wear of the tools, by pre-arrangement. When tools are condemned as useless, they should invariably be broken up before disposal, otherwise these old tools will be brought up and returned into store on every possible excuse in exchange for good ones issued to the works.

CHAPTER IV.

CUTTINGS.

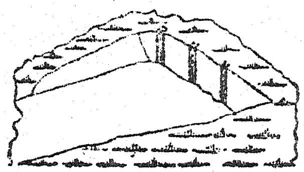
58. A great deal of unnecessary expenditure can be avoided if the Engineer when designing and carrying out a work such as a railway, road or canal considers his cuttings and embankments, and tries to utilize the earth removed from a cutting on the embankments. The ideal case is the one where the earth removed from the cutting is equivalent to that needed for the embankment, but in India where carriage from one place to another cannot always be done with trucks and rails, and where land and labour are cheaper than in Europe, it frequently happens that it is more economical and work can be carried out more quickly by spoiling much of the earth removed from a cutting, and obtaining the earth required for the bank from outside borrow pits.

A little alteration in the alignment or in the design will often make a great difference in the amount of work to be done. On a canal there is always an economical depth of cutting which will supply the requisite amount of earth for the banks and any great variation from this amount will not tend towards economy. On railways, roads and canals there is a certain slope which is most suitable, but there is generally a fair working range, and by careful adjustment of the slopes within this range, considerable economy can be effected. In the case of a canal the position of a fall, and the depth of a fall will make a great difference in the amount of work which has to be carried out. There is usually a site for the fall which is the best from an irrigation point of view, and this must not be sacrificed without good reasons. The smaller and more numerous the falls that are designed the less will be the amount of earthwork that is required, but the cost of the masonry works will be greater.

In England, previous to opening a cutting, it is usual to strip off the upper soil or vegetable mould from the ground to the depth of from 3 to 6 inches, and to preserve it for the purpose of re-soiling the slopes, in order that grass may grow on them readily. If the cutting happens to be through grass land, the sods of turf are taken off and kept rolled up with the grass inside in a moist shady place. In this way they may be preserved for some time, and will take root readily again on the new slopes.

59. A cutting in a hill side of considerable height is usually begun, (if the earth will stand for any time with vertical sides) by cutting a fair vertical face to the work at right angles to the direction of the cutting. From this face, vertical niches, as shown in the figure, are made, wide enough for one man to ply his pickaxe, after which very little labour is required to separate the masses between the niches, the earth in the meantime being carried off by baskets, barrows, or wagons.

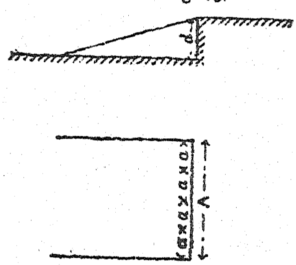
Fig. 18.



Another method is to undermine the earth at the bottom of the cutting by picks, etc., and then with crowbars to work from the top of the cutting till large masses of earth are levered off. The earth is then broken up at the bottom of the cutting and removed in the most convenient manner. Frequently the diggers form a close line across the face of the cutting, and with picks and other tools throw the earth backwards. It is then removed by another party with baskets.

60. If a road, say A wide, see *Fig.* 19, has to be cut through a hill or any other cutting has to be made, progress is limited by the number of men that can be put on the breadth or face of the excavation and by the rate at which a single workman can advance the part of the face of the cutting he works at. Therefore the closer we can put the workmen together, the less of the face will fall to each man's share, and the faster the work will progress; we must remember of course that if men are put too close together they get in each other's way, and so work is impeded.

Fig. 19.



61. Thus if a is a convenient breadth for men to work in, and d is depth of cutting, each man has a surface ad to work on, and if his daily cubic task is C, then the distance he will advance a day is $\frac{C}{ad}$ and the whole cutting can advance at this rate only, and no faster by any arrangement whatsoever.

62. The order in which portions are taken out from a cutting is of small importance, hence the most convenient working method should be

adopted. The final dressing of the slopes is generally left to the end, or until the arrangements for protecting them, or for letting water into the channel, are ready to be put in hand. The dressing should certainly not be commenced till all the arrangements for draining the land on either side of the excavations are complete, as any water which runs down the slopes will cut them into channels which will be difficult to repair afterwards. The mass of the work, i-e., the centre part, should be done first, and then the slopes rapidly finished up afterwards.

63. *Figs.* 1 and 2, Plate I, show the consecutive operations required for heavy cutting. The cutting starts from the left. As the work proceeds into the hill, and the width is increased to provide for slopes, it becomes desirable to run a gullet, or vertical excavation, wide enough for one line of temporary rails along the centre line, in order to bring the greatest number of wagons into use. The wagons in the gullet are filled either directly by diggers in front of them or by barrows on both sides, working on a stage above them. As the height of the hill increases, side tracks are laid down on this second stage inclining down to the lower level. On these lines the full wagons descend on one side, and the empty ones ascend on the other. As the lines are shown in *Fig.* 1 it is possible to do this for only the central gullet except with a great deal of shunting. The sketch only shows a short length of cutting where of course there would be no necessity to use one side for empties, and the other side for full trucks, but where this is advisable a greater length of flat space is required between the two gullies to give room for trucks to cross from one side to the other.

In executing a cutting in this manner, the bed should always be kept inclined upwards, so as to allow of any water which may collect at the bottom being easily conducted out to the end of the work. This should be done irrespective of the slope which the formation bed is finally to receive, as it may easily be adjusted after the cutting is carried right through the hill.

It is evident that many cases might occur, where the above mode of operations could not be followed, as it might be necessary to lift the earth up out of the excavation to the level of the ground. This might, for instance, be the case where a railway had to be carried through a long cutting; and to save time it might be necessary to open ground at intermediate points as well as from the two ends. This, however, would not often happen, as the expense would of course be very much increased by such a proceeding. In forming canals, however, in a flat country like India, it is almost always necessary to raise the earth up

rom its bed, as in but few cases would it be possible, or desirable, to ring out the bed of the canal anywhere to the level of the country.

64. **Horse run.**—When the bank up which soil has to be moved is necessarily very high and steep, as, for example, if it should make an angle with the horizon of 25° or 30°, and is perhaps 40 or 50 feet high, an expedient called a horse run is sometimes resorted to. That is, two tracks of planks are placed upon the slope, and fixed there by stakes driven into the ground and nailed or spiked to the planks. These tracks should be placed at a distance apart that rather exceeds the slope of the excavation. Opposite the top of each track a post, with a large iron sheave or pulley fixed to it, is firmly let into the ground. The wheel-barrows used are of the same construction as those before described, but much deeper and larger, and a strong iron staple is fixed in the front of each for receiving the hook of a rope passing from the barrow in the bottom up the slope through the two sheaves and terminating in a hook at the second barrow upon the top of the slope, in such manner that the upper barrow cannot be lowered without bringing up the lower one and *vice versa*. A straight horizontal horse-track is formed just behind the posts, extending from one to the other of them, and a strong iron ring being lashed to that portion of the rope that is constantly between the two posts, the traces of a horse are hooked into it, and as the animal is driven backwards and forwards, he will elevate one and depress the other of the barrows alternately. The lower barrow being detached from its rope is placed where it may be loaded with soil, when it is wheeled to the foot of the inclined plane, and the rope being hooked on to it, a signal is given to the driver above to start the horse, when he draws the loaded barrow up the slope, a man following behind at the handles to guide it, and keep the barrow legs above the ground. While the loaded barrow is thus ascending, the empty one descends, guided in like manner by the man who had before accompanied it upwards, his weight and that of his barrow compensating nearly for the man and barrow ascending on the other track. The ascending man has to walk in a direction nearly perpendicular to that of the inclined plane, so that he can exert no strength or muscular action to assist the barrow in its ascent: but, on the contrary, a large portion of his weight is added to that of the barrow ; but this is compensated for by the descending man, who comes with this face forwards, and by hanging on to the arms of his barrow, throws his weight upon it so as nearly to equalize the weight of the ascending barrow.

The horse run is a slow and expensive method of raising soil and is hardly ever used in India; it should not be resorted to except in cases of

CUTTINGS.

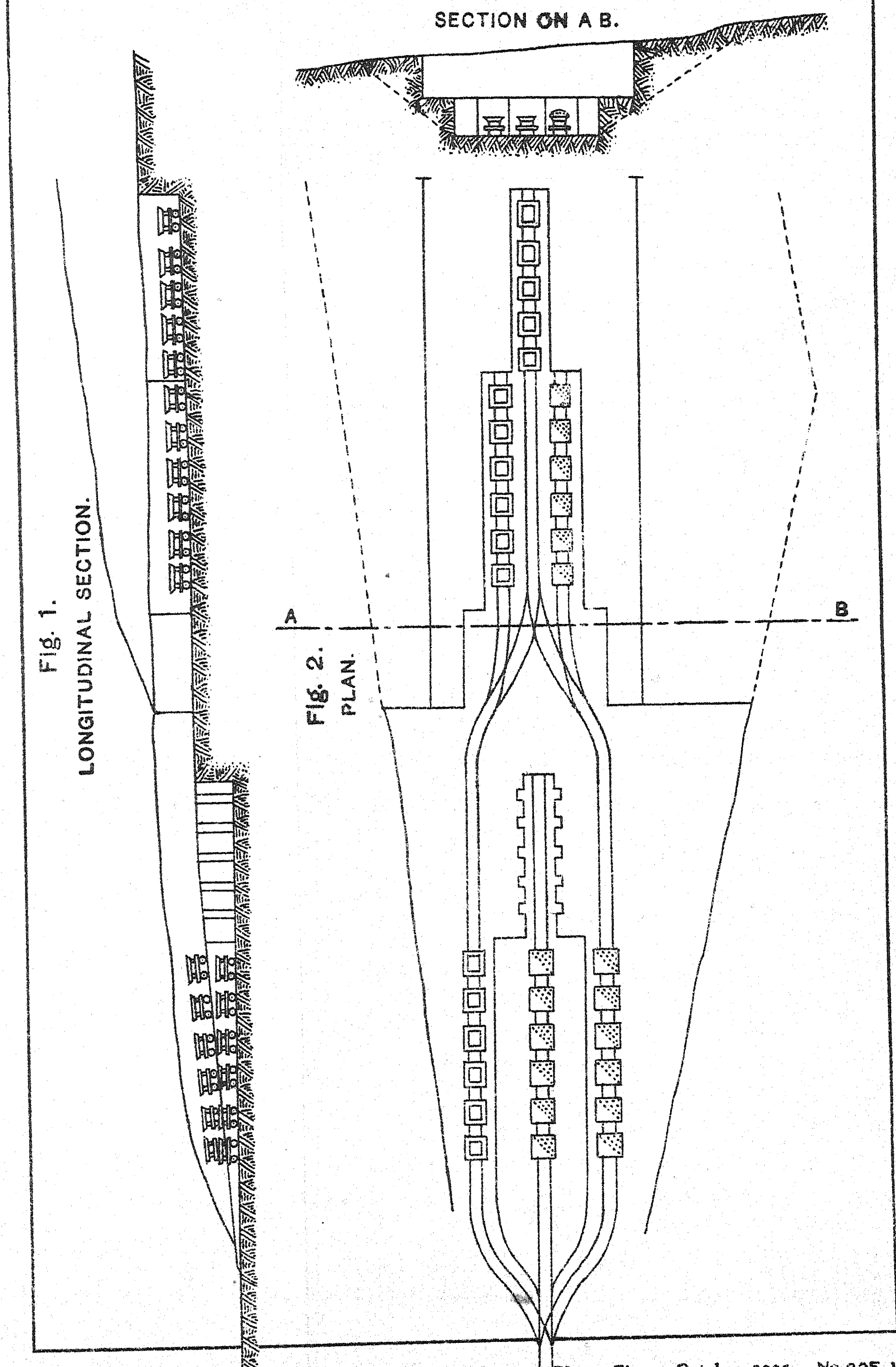
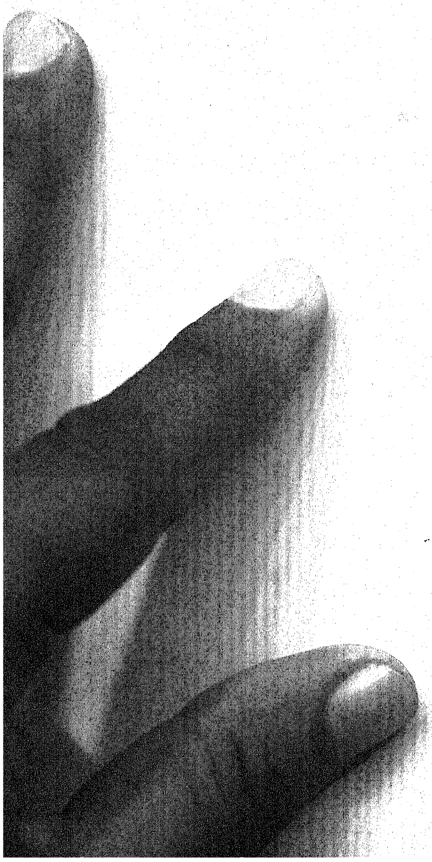


Photo. Zinco., October, 1925 —No. 835-16



necessity; but with all its disadvantages, it is cheaper than common barrow work when the excavation becomes deep, because when the plank track for wheel-barrow must be made very long for procuring the necessary gradual slope, it increases the number of sloping or short stages to such an extent that it becomes very expensive.

65. **Stages.**—Another mode of raising soil out of deep excavations, without a horse run, is by casting up by stages. A scaffolding is formed with as many boarded platforms, at five feet above each other, as will reach the required height. These are placed one beyond the other like the steps of a staircase, and a man with a shovel is placed on each. The lowest man, who digs the soil, throws it by his shovel on to the lowest stage, and the man stationed there delivers it in like manner on to the stage next above him, and so on in succession, until it reaches the surface This method is a very slow one, and not to be recommended, and is seldom adopted in India. It would be cheaper to make an easy track up the slope and remove the earth by baskets.

CHAPTER V.

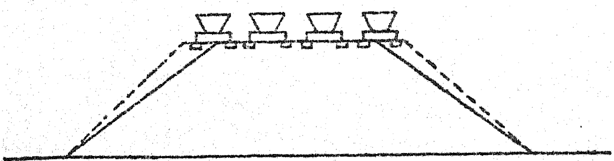
EMBANKING AND PUDDLING.

66. The best materials for road embankments are those whose frictional stability is the greatest and in which the least settlement takes place, such as shivers of rock, shingle, gravel, and clean sand. Wet clay, vegetable mould, and mud are inferior to the above for road embankments, though superior if the embankment is required to retain water as in the case of canal and tank works. A light alluvial soil which contains a fair proportion of fine sand, and not too high a proportion of clay is the best earth to use in the construction of high reservoir or tank embankments. A soil which will make good bricks is generally a suitable soil.

Soils which contain a high percentage of clay and soils which contain any alkaline salts should be avoided. Should their use be unavoidable those that contain a high percentage of clay should be mixed with sand or *bajri*, or encased in a thick layer of sand, shingle, *bajri* or shale.

Embankments may be made in three ways :—1st, in one layer ; 2nd, in two or more thick layers ; 3rd, in a succession of thin layers. The first is the cheapest and quickest method, and is the one followed in most cases. The earth is raised at once to its full height, and thrown down at the commencement of the embankment ; and, as the work proceeds it is placed at the extremity of the completed portion. The objection to this method is that, not having been rammed or laid uniformly the earth is subject to a greater amount of settlement, and after completion of the work it takes a longer time to settle permanently than if it had been formed in courses and rammed. Hence a road or other work constructed on the surface of banks so formed, is liable to suffer subsequent derangement and injury. There is not the same objection to the use of this method when the earthwork is to be allowed to stand for a length of time before being

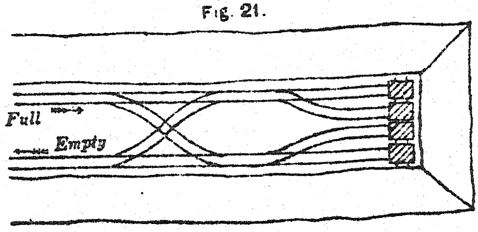
Fig. 20.



used for its ultimate purpose. To accelerate the construction of an embankment, the width on top is sometimes made greater than the

final width, so that room is provided for bringing forward a greater number of earth wagons than would otherwise be possible. The bank is afterwards reduced to its proper form and dimensions by cutting away the superfluous earth at the sides If a railway is used to build a bank such as is shown in *Fig.* 20, there is no necessity to lay down four lines of rail in order to run four wagons abreast at the head of the embankment, to ensure even progress. Two lines are sufficient, each having two termini, and what is called a double crossing as shown in *Fig.* 21. The train with the full trucks can then be brought up one line, the trucks emptied evenly across the whole width of the bank and returned empty back by the other line as is explained in the figure Arrangements must be made to prevent any delay at the tip head. Where the embankment is not to be very broad, no tipping over the sides should be allowed; for the earth so tipped is liable afterwards to slip off.

Fig. 21.

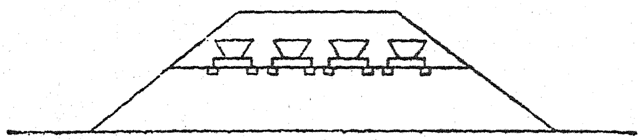


The rails are continually pushed on along the bank thus formed, and trucks continue to tip from their extremities over the end of the bank, which thus gradually increases in length and consequently in height also, while on the descent into the valley: but instead of being formed in horizontal layers, it is made in layers sloping parallel to the "tiphead," as the end of the bank at any time is called This of course does not make so solid a bank as when it is constructed in thin parallel layers, when each layer is trodden by the workmen making the next, but the tip is a cheaper and more expeditious method. For road and railways this method is generally good enough, but for banks which have to hold up water it should never be adopted.

67. The second method in use for forming embankment, is to make the bank of half the proposed height at first; the greater breadth of surface at the lower stage affording an enlarged space, admitting of the employment, in a similar manner to that described above, of a greater

number of earth wagons than could be brought to the front at one time on the top of the embankment (when of the full height). The layer is then left for sometime to settle before commencing another. This system

Fig. 22.

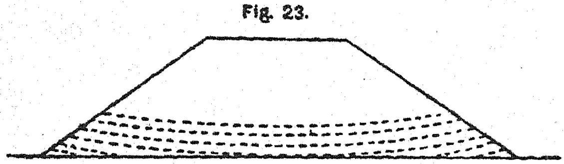


involves much additional time and labour, and is seldom employed. It is, however, useful in making embankments of hard clay or shale, which consist at first of angular lumps which do not form a compact mass until partially softened and broken down by the action of the air or moisture.

68. The third mode consists in laying down the earth in small uniform layers from 6″ to 12″ in thickness, and ramming each layer before the next is laid down. This method is unquestionably by far the best where density and stability are required, such as in high canal or tank embankments; it will however be slower and more expensive than the other methods. This is the method usually followed in India, where embankments are generally made with earth which is carried in baskets by coolie labour. It is recommended that these layers should be concave, (see fig. 23) this manner of construction having been found to contribute greatly to the prevention of slips in new embankments.

This process is necessary in such cases as in the filling in behind

Fig. 23.



retaining walls, and in making sides of canals; or embankments for tanks, for which purposes it should always be adopted.

69. In each case the circumstances must determine the way in which the bank is to be made. The least expensive way by which the required work can be done well is the method adopted here as in all other cases.

In all embankments large clods of earth should either be broken up before they are put into the truck barrow, or basket, or immediately they are deposited at site. If this is not done, the bank will be full of hollows

and be very rotten. In high and important embankments it is a good thing to insist on the clods being broken up before they are removed from the borrow-pits, and being again broken up when laid on the bank. There is nothing which requires more attention, and which contractors are more liable to scamp than clod-breaking.

Ramming is important and useful, but a bank that is laid in uniform layers with no clods, even though it is not rammed, will, after a few rainy seasons, settle down and be superior to the bank which has been well rammed, but where no attention has been paid to clod-breaking.

Donkeys are frequently used for the carriage of earth from the borrow-pits to the bank, and unless precautions are taken the bags in which the earth is carried are filled with clods. The donkey-men (to save themselves trouble) say that the clods are more convenient for carriage, but there is really no difficulty in carrying the broken earth.

70. The amount of care which must be given to the consolidation of a bank depends on the conditions and requirements of each case. For instance, a large canal embankment requires more care than a bank of the same height for a small channel. A tank embankment made of light loamy soil requires much less care than a similar bank of black cotton soil and so on.

The opinions of different Engineers vary regarding the respective values of ramming, clod-breaking, and the uniformity and thickness of layers. In some provinces it is customary to roll each layer of a high tank embankment with a steam-roller, while in other parts of India steam rollers are never used. Kinds of soil, the labour available and methods of carrying out work, the climatic conditions all vary greatly in different parts of India, so it is not advisable to lay down any hard-and-fast rules. Where a steam-roller is employed to ram the banks it is absolutely necessary to keep the layers uniform, and undoubtedly this is one of the greatest advantages of the system. Unless however the layers are very thin (and this is often impossible) any form of ramming or rolling, however thorough it may be, does not necessarily break up all the clods. The money which is used on steam-rolling or on other elaborate methods of ramming can therefore often be better spent on the thorough breaking up of clods, and in insisting on the uniformity of the layers.

In banks of any importance it is advisable never to allow the earth to be tipped from trucks on the final site, as then uniform horizontal thin layers are impossible. The earth should be re-lifted and carried in baskets to the correct site. For this reason carriage by donkeys or oxen is more satisfactory than carriage in trucks. The coolie or donkey climbs

up the bank and deposits the earth in the exact spot where it is required, and passing backwards and forwards over the work greatly assists in breaking up the clods and ramming the earth.

71. A new bank cannot be consolidated till it has been thoroughly saturated with water, but water is seldom available till the rains break. Important embankments should therefore never be rushed; they should be given the benefit of as many rainy seasons as possible and consolidated by the methods mentioned later.

The Solani embankment of the Ganges canal is an important engineering work and the method adopted, which has proved most successful, may be roughly described as follows:—

"The bank was made to a certain height in a series of narrow longitudinal and cross banks, making the number of tanks as it were; these received the rainfall of the year and were thus consolidated. Next season the hollows were filled in, and another stage of tanks made for next season's rains."

This is the principle that should be employed in a modified form on all banks which have to hold up water.

The top surface of the bank should be divided before the rainy season, into a series of small compartments bounded by earthen ridges about 12" high. The rain which falls inside each compartment is then held up and soaks into the bank and assists in the rapid and efficient consolidation. These ridges and compartments require constant repairs during the rainy season. The ridges must be repaired and the hollows that form should periodically be filled in from places that have not sunk as much. If this is not done, the whole of the rainfall which falls on one or more of the compartments may run uselessly away, or may collect in one spot and consolidate it alone, leaving the other parts untouched. The aim should be to use the rainfall for the uniform consolidation of the whole of the bank erected during the year. It frequently happens in the construction of large tank embankments that a gap has to be left to run off the drainage which collects from the catchment area above the bund. The embankment may take four or five years to construct, and during this time it will have more or less settled down. The gap however must be constructed in one working season, and there will be very little rain to assist the consolidation till water commences to be held up behind the work. The settlement is therefore bound to be uneven and unless great care is taken the bank is liable to be breached, and especially is this the case near the junction of the new and old work.

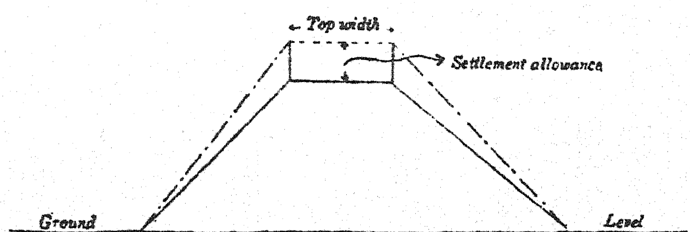
In cases of this sort it is necessary to employ special precautions during construction, with the object of making the new and the old bank as uniform as possible, and of ensuring more or less even consolidation. The layers must be thinner than usual, ramming must be very carefully done, the earth must be broken up finely and, wherever practicable, the layers should be saturated with water. In most places some water can be held up during the rainy season, and then can be pumped on to the embankment to saturate the layers of earth.

The winter rains are also useful, the whole of the run-off from the catchment area can generally be collected above the embankment and used later on for saturating the work as it progresses. The junction between new and old works, such as a bank against the side of a hill, or a gap against the portions of the completed embankment, must be specially considered. The slopes of the hillside or of the completed work should be cut into steps which form an easy slope. The easier the slope is the better it will be ; steep slopes are a source of danger, and it is extraordinary how careless some Engineers can be in this matter.

72. All made earth is liable to settle, that is, the surface to sink, and the whole volume to contract, after completion of the work. The amount of settlement depends on the nature of the soil, the height of the work, and the method in which it was formed. It will be less if the earth has been well rammed ; and, in works of different dimensions all other circumstances being alike, it has been found to vary nearly as the cube of the height.

There is often much carelessness regarding settlement and it is probable that many breaches in newly-made embankment have been caused by an insufficient allowance being made for settlement. In appendix V are given the results of some experiments made in the United Provinces. These are not given as a guide, but merely to draw

Fig 24.



Full lines show final section of bank.
Dotted lines show section of bank to be constructed.

attention to the question, and, unless an Engineer has had great experience on this subject, he is advised to make his own experiments before he starts the work. Figure 24 shows the proper method of constructing a bank after the settlement allowance has been fixed.

When it takes several years to construct a bank it is always a difficult question to decide as to how much settlement should be allowed for. Settlement will go on every year and the amount varies according to the precautions which have been taken during the rainy season. Unless some method has been adopted, the correct allowance for settlement can only be roughly gauged. The best plan is to settle from practical experiments what the settlement per foot of height is likely to be. The work is then constructed according to figure. Before and after every rainy season levels should be taken of the bank and the amount of settlement should be noted and allowed for in the section of the bank which remains to be made.

The settlement of clean gravel or sand is hardly appreciable, the settlement of other earths varies according to their quality. Owing to the incompressibility of clean sand, it is often used for filling deep foundations in made soil, in order to reduce the cost of a building. When digging the foundation of the Saharanpur Dispensary, made soil was found to a depth of some 16 feet; the trenches were filled, to within 2½ feet of the surface, with clean damp river sand, laid in layers, and slightly rammed with pointed rammers; over this the usual 2 feet of concrete was consolidated and the superstructure completed. The roofs of this building consist of brick arches. No cracks or settlement of any kind have appeared since the dispensary was completed many years ago.

73. In embankments, as has been noticed before, the side slopes must be less inclined than those of excavations in soil of the same character; the earth having been loosened and so rendered incapable of resting freely at the same high inclination at which it stood while undisturbed in its original position in the ground. To ensure stability, an earthen embankment should have slopes which correspond to the angle of repose of the particular soil of which it is made, but in practice the slopes are sometimes made steeper for the sake of economy. In all cases where embankments are exposed to the action of water, especially if agitated by wind, as in the case of a sea dyke, the exposed slopes should be very long and flat, say 5 to 1.

74. All side slopes, whether of excavations or embankments, which it is desired to preserve permanently at a uniform inclination, should, on completion, be faced in some manner to protect them from the weather;

and, in the case of artificial channels, dykes, etc., from the action also of water. Grassing the surface with whole turf or with a covering of stiff clay is a common method in Europe, but is seldom practicable in India. When sods cannot be procured, it is expedient to plant the ground with *dub* grass; the grass will grow best on surface soil, with which the face of the embankment should first be dressed. In the case of embankments which are exposed to the action of water a covering of brushwood, fascines, or of hurdles is used, in some cases with good effect; and in Holland ropes of straw or grass are pegged down so as to cover the whole surface, a measure often applicable in India.

Large thin slabs of stone laid on the slope are in frequent use in the Bombay Presidency for protecting the sides of the roads and embankments, or the sides may be pitched with rough stone carefully packed, etc., The sides of cuttings through rock of a slaty structure, which shows a tendency to break on the surface and to slip, may be cut in rough steps instead of a slope, and these, if necessary, may be afterwards covered with earth, and grassed.

Large tanks and reservoir embankments are subject to heavy wave action, and unless they are protected they are liable to be rapidly cut away. The usual protection is stone pitching one to two feet thick with three to six inches of small stone at the back to prevent the waves as they rise and fall from sucking up the earth.

75. **Slopes.**—All side slopes, whether of excavation or embankment, should on completion be faced either by grass or pitching in some manner to protect them from the weather, but this is only practicable in India on large works, and therefore it is all the more necessary that the drainage should be most carefully attended to. If that is not done, not only will rain-water collect and run down the slope at places, making ugly holes which are difficult to repair, but if rain-water is allowed to accumulate and sink in through the top of an embankment, the earth below will become soft, and will be unable to bear the weight above it, when portions of the slopes may slip down. A gentle slope, by giving a broad base, is of assistance in banks which are liable to subsidence.

All kinds of earth containing clay become soft when wetted and are unable to bear pressure, whilst embankments composed of most kinds of rock, or of gravel, or of sand, are not softened by the action of water. Sand being liable to erosion, must have its surface protected from wash of all kinds, and embankments formed of clayey earths must have their

To prevent slopes from being damaged by surface drainage, water should never be allowed to collect. It should be so arranged that whatever rain falls can be carried off directly over the slopes that belong to that surface, when the drainage will pass off almost imperceptibly and do no damage. If, however, the drainage is allowed to collect for only a few feet on the length of either the horizontal portion or the slopes, a small stream is formed (its size depending on the area of drainage collected and the rainfall) and the injury done to the side slopes is limited only by their power to resist this stream. If for any special reason the surface drainage has to be collected in any quantity and passed down the side slopes, the drains on the slopes should be pitched or otherwise protected.

It will be readily seen that only an inappreciable quantity of drainage passes off over the side slopes if the water is not allowed to collect. Supposing the top of the embankment to be 30 feet wide, and an inch of rain to fall in an hour, the depth of water passing over the edge of the bank at any point during this heavy fall will be the 1/120th part of an inch; supposing the water to flow off at the rate of one foot per second in one direction only; or 1/60th of an inch if flowing at half a foot a second an inappreciable quantity for harm; but if this water is allowed to collect in a drain, it will soon form a strong stream, capable of doing a great deal of damage.

76. All cuttings must be made with a rise as they progress, so as to drain the water out of them. For all kinds of earthwork it can be seen that proper precautions for drainage of every sort are never to be lost sight of. Soil frequently melts away under the action of water, and very great damage may be caused in a short time by neglect to take precautions at first.

77. When the earth is so soft that an embankment made in the ordinary way would sink in it, different expedients are employed according to the difficulty to be overcome. It may be sufficient to dig side drains parallel to the side of the intended work, and so, by carrying off all the water, consolidate the ground lying between them. Sometimes it may be advisable to dig out of the soft ground, and make a regular foundation of stable material on which the embankment will stand. Or, if the soft ground has, at no very great distance beneath the surface, a firm substratum, a foundation of stones or gravel may be laid going right down to this base. Sometimes short piles which are driven through the soft earth will enable the earth to stand the requisite pressure.

In the celebrated example of Chatmoss, which was from 10 to 34 feet deep, containing nearly double its bulk of water George Stephenson formed a secure foundation for heavy railway traffic at a cost below the

EARTHWORK EXCAVATION TABLE.

Areas of Side Slopes to nearest Square Foot.

d	$d^2 \times 0.5$	$d^2 \times 1$	$d^2 \times 1.5$	$d^2 \times 2$	$d^2 \times 3$	d	$d^2 \times 0.5$	$d^2 \times 1$	$d^2 \times 1.5$	$d^2 \times 2$	$d^2 \times 3$	d	$d^2 \times 0.5$	$d^2 \times 1$	$d^2 \times 1.5$	$d^2 \times 2$	$d^2 \times 3$	d	$d^2 \times 0.5$	$d^2 \times 1$	$d^2 \times 1.5$	$d^2 \times 2$	$d^2 \times 3$
0·1						5·1	13	26	39	52	78	10·1	51	102	153	204	306	15·1	114	228	342	456	684
·2						·2	14	27	41	54	81	·2	52	104	156	208	312	·2	116	231	347	462	693
·3						·3	14	28	42	56	84	·3	53	107	159	212	318	·3	117	234	351	468	702
·4						·4	15	29	44	58	87	·4	54	108	162	216	324	·4	119	237	356	474	711
0·5				1	1	5·5	15	30	45	61	91	10·5	55	110	165	221	331	15·5	120	240	360	481	721
·6			1	1	1	·6	16	31	47	63	94	·6	56	112	169	225	337	·6	122	243	365	487	730
·7			1	1	1	·7	16	32	49	65	97	·7	57	115	172	229	343	·7	123	247	370	493	739
·8		1	1	1	2	·8	17	34	50	67	101	·8	58	117	175	233	350	·8	125	250	374	499	749
·9		1	1	2	2	·9	17	35	52	70	104	·9	59	119	178	238	356	·9	126	253	379	506	758
1·0	1	1	2	2	3	6·0	18	36	54	72	108	11·0	61	121	182	242	363	16·0	128	256	384	512	768
·1	1	1	2	2	4	·1	19	37	56	74	112	·1	62	123	185	246	370	·1	130	259	389	518	778
·2	1	1	2	3	4	·2	19	38	58	77	115	·2	63	125	188	251	376	·2	131	262	394	525	787
·3	1	2	3	3	5	·3	20	40	60	79	119	·3	64	128	192	255	383	·3	133	266	399	531	797
·4	1	2	3	4	6	·4	20	41	61	82	123	·4	65	130	195	260	390	·4	134	269	403	538	807
1·5	1	2	3	5	7	6·5	21	42	63	85	127	11·5	66	132	198	265	397	16·5	136	272	408	545	817
·6	1	3	4	5	8	·6	22	44	65	87	131	·6	67	135	202	269	404	·6	138	276	413	551	827
·7	1	3	4	6	9	·7	22	45	67	90	135	·7	68	137	205	274	411	·7	139	279	418	558	837
·8	2	3	5	6	10	·8	23	46	69	92	139	·8	70	139	209	278	418	·8	141	282	423	564	847
·9	2	4	5	7	11	·9	24	48	71	95	143	·9	71	142	212	283	425	·9	143	286	428	571	857
2·0	2	4	6	8	12	7·0	25	49	74	98	147	12·0	72	144	216	288	432	17·0	145	289	434	578	867
·1	2	4	7	9	13	·1	25	50	76	101	151	·1	73	146	220	293	439	·1	146	292	439	585	877
·2	2	5	7	10	15	·2	26	52	78	104	155	·2	74	149	223	298	447	·2	148	296	444	592	888
·3	3	5	8	11	16	·3	27	53	80	107	160	·3	76	151	227	303	454	·3	150	299	449	599	898
·4	3	6	9	12	17	·4	27	55	82	110	164	·4	77	154	231	308	461	·4	151	303	454	606	908
2·5	3	6	9	13	19	7·5	28	56	84	113	169	12·5	78	156	234	313	469	17·5	153	306	459	613	919
·6	3	7	10	14	20	·6	29	58	87	116	173	·6	79	159	238	318	476	·6	155	310	465	620	929
·7	4	7	11	15	22	·7	30	59	89	119	178	·7	81	161	242	323	484	·7	157	313	470	627	940
·8	4	8	12	16	24	·8	30	61	91	122	183	·8	82	164	246	328	492	·8	158	317	475	634	951
·9	4	8	13	17	25	·9	31	62	94	125	187	·9	83	166	250	333	499	·9	160	320	481	641	961
3·0	5	9	14	18	27	8·0	32	64	96	128	192	13·0	85	169	254	338	507	18·0	162	324	486	648	972
·1	5	10	14	19	29	·1	33	66	98	131	197	·1	86	172	257	343	515	·1	164	328	491	655	983
·2	5	10	15	20	31	·2	34	67	101	134	202	·2	87	174	261	348	523	·2	166	331	497	662	994
·3	5	11	16	22	33	·3	34	69	103	138	207	·3	88	177	265	354	531	·3	167	335	502	670	1005
·4	6	12	17	23	35	·4	35	71	106	141	212	·4	90	180	269	359	539	·4	169	339	508	677	1015
3·5	6	12	18	25	37	8·5	36	72	108	145	217	13·5	91	182	273	365	547	18·5	171	342	513	685	1027
·6	6	13	19	26	39	·6	37	74	111	148	222	·6	92	185	277	370	555	·6	173	346	519	692	1038
·7	7	14	21	27	41	·7	38	76	114	151	227	·7	94	188	282	375	563	·7	175	350	525	699	1049
·8	7	14	22	29	43	·8	39	77	116	155	232	·8	95	190	286	381	571	·8	177	353	530	707	1060
·9	8	15	23	30	46	·9	40	79	119	158	238	·9	97	193	290	386	580	·9	179	357	536	714	1072
4·0	8	16	24	32	48	9·0	41	81	122	162	243	14·0	98	196	294	392	588	19·0	181	361	542	722	1083
·1	8	17	25	34	50	·1	41	83	124	166	248	·1	99	199	298	398	596	·1	182	365	547	730	1094
·2	9	18	26	35	53	·2	42	85	127	169	254	·2	101	202	302	403	605	·2	184	369	553	737	1106
·3	9	18	28	37	55	·3	43	86	130	173	259	·3	102	204	307	409	613	·3	186	373	559	745	1117
·4	10	19	29	39	58	·4	44	88	133	177	265	·4	104	207	311	415	622	·4	188	376	565	753	1129
4·5	10	20	30	41	61	9·5	45	90	135	181	271	14·5	105	210	315	421	631	19·5	190	380	570	761	1141
·6	11	21	32	42	63	·6	46	92	138	184	276	·6	107	213	320	426	639	·6	192	384	576	768	1152
·7	11	22	33	44	66	·7	47	94	141	188	282	·7	108	216	324	432	648	·7	194	388	582	776	1164
·8	12	23	35	46	69	·8	48	96	144	192	288	·8	110	219	329	438	657	·8	196	392	588	784	1176
·9	12	24	36	48	72	·9	49	98	147	196	294	·9	111	222	333	444	666	·9	198	396	594	792	1188
5·0	13	25	38	50	75	10·0	50	100	150	200	300	15·0	113	225	338	450	675	20·0	200	400	600	800	1200

average of the other parts of the line in the following manner :—Drains were cut about every five yards apart, and when the moss between them was quite dry it was used for the embankment. On this were laid hurdles either in single or double layers, and over them the ballast. By thorough draining in this way, cutting as deep as nine feet, and embankments as high as 12 feet were formed in a quagmire in which an iron rod would sink by its own weight.

78. Notwithstanding that an embankment may, in many cases, be formed without expense, it generally happens that some additional labour or care has to be bestowed upon the work, for which a remuneration is always allowed. Thus, all removal of soil is paid for according to the distance it is carried, and if that distance should be increased for the making of an embankment, instead of throwing the earth at the sides of the work as originally intended, this would constitute a fair item of charge.

Again, should the earth be required to stand against water, as stated before, it should be laid in regular layers or strata, and rammed, in order to break the lumps and make the work more solid and compact. This would be an additional charge. The punning is performed by rammers of cast-iron* or wood hooped with iron to prevent their splitting, worked by men ; a short straight 3-inch *bullie* of hard wood, bluntly pointed at the thick end (if necessary shod with iron) and of suitable weight, makes a good punner for earthwork, as it breaks the clods and consolidates the earth more effectively than the flat rammer. When ramming is adopted, the courses of earth should never exceed nine inches in thickness, otherwise the blows of the rammer will have little or no effect on the under part of the stratum, and whether the operation of punning is performed or not, it is impossible for the workmen to carry and deliver the soil on to an embankment with the same nicety and precision as to form, as can be obtained in excavating soil from the earth. All embankments, therefore, must be rugged and uneven when first formed, and they require what is called trimming or dressing, to reduce them to even and fair surfaces. The trimming consists of filling hollows and cutting off protuberances, and this accordingly is charged for separately, at a rate agreed upon and regulated by the superficial measure of the surface of the embankment, instead of by its solid contents. The same kind of trimming takes place upon the surface of all excavations, but it is seldom made a separate charge, being included in the price for doing the work and is considered as a necessary finish to it. Most Engineers however prefer

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*. Cast-iron rammers, weighing 12 lbs. are supplied at the Roorkee Workshops.

to give one rate for the completed work, whether it be the excavation of a cutting or the construction of an embankment. The dressing, ramming, and other specifications which may be made are considered in the rate, and the full rate is not paid till the work has been completed.

When the ground has a steep side-long slope, it is generally necessary to cut its surface into steps before making the embankment, in order that the latter may not slip down the slope. The best position for these steps is at a right angle to the direction of the pressure of the earth upon them. They should incline to the horizon, in an opposite direction to the slope of the natural ground.

79. As a practical illustration of the above, the following extract from Colonel Rundall's Chatham Lectures, explaining the failure of the embankment of the Red Hills Lakes, will show the necessity both for proper surface drainage in embankments made with certain kinds of soil, and that when new work has to be added to old, the junction should be made homogeneous. He says:—"The soil on which the embankment for the reservoir stands consists principally of 'laterite,' a formation only met with in India, I believe, and which may be described as a mixture of ferruginous gravel and clay, but other soils are intermixed with it, varying from good stiff clay to fuller's earth; and it was owing to some of the latter having been, probably inadvertently, used, that nearly 440 feet in length of the bank slipped. As, it is as useful for Engineers to learn why or how failures occur, as it is to be taught wherein success lies, I will just describe the state of this embankment a little more particularly. The water level on the date on which I saw it was 12½ feet below the crest of the bank, being two and a half feet lower than the maximum level at which it stood at time the slip occurred. The bank had been opened out two feet below the then level of the water in the tank, and the soil of which it was composed exposed to view. It was of a very inferior description, resembling fuller's earth with an admixture of sand. It was perfectly saturated with water, and, consequently, in a semi-fluid state. How the water had got there was not quite clear, but it was owing most probably to the soakage of the rain which had fallen on the bank itself during a cyclonic storm that had occurred just previously. It could not have been owing to any leakage through the inner slope, as the clay puddle which had been laid on the inner face with its stone pitching was undisturbed. The slips took place where the newly-raised portion rested on the old bank, and were—there seemed little room to doubt—owing to the mixture of the inferior soil before alluded to. A complete breach was prevented by the Engineer-in-charge breaking up the crest of the waste weir for two and a half feet, and so relieving the pressure against the bank.

"The lessons to be learnt from this accident are first, the necessity of having the mass of the embankment composed of as homogeneous material as possible, and next, that when the capacity of a reservoir has to be increased by raising the height of the bank, the importance of securing a perfect cohesion between the new and the old work. To this end the surface of an old bank should be well broken up before any new soil is laid thereon."

To this may be added the necessity of surface drainage and of puddling the surface, as well as the water face, when the bank is made of material liable to become semi-fluid or soft by the percolation of surface water. As a precautionary measure, banks of such material should be given an extra width of base to reduce the vertical pressure and prevent the bank subsiding in the event of drainage finding its way into it. Foundation drains would also be useful.

80. **Puddling.**—If the excavation or embankment is intended to retain water, another process, called puddling, may be requisite. Some soils are of a nature capable of holding water without any artificial assistance, and clay or loam are of this character; others again, as sand or gravel, and the debris of stony rocks, absorb all the water that may be deposited above them, or they permit it to percolate or run through them. This likewise is the case with almost all artificial embankments when first made, even though they may have been punned in their courses and every pains taken in their construction. It is a matter of great importance in the construction of canals, that they should retain and hold all the water thrown into them, particularly where water is scarce, or where their elevation is such that the escape of it might prove not only detrimental to the adjoining lands but to the safety of the bank itself. No canal can be formed without raised embankments in some parts of it, so strict attention to the process of puddling, by which alone the escape of water can be prevented, is of the greatest importance.

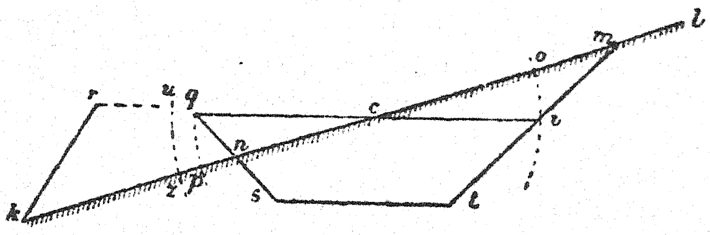
No cheap and common material is found to oppose the filtration and passage of water so effectually as a soft loamy clay, when it is well worked or kneaded into a soft paste with water, called "puddle," and is not permitted to dry again. Even if a little fine gravel is mixed with the clay it seems to hold better, and to assist the kneading process and prevent cracks. The silt or natural deposit of tidal rivers is also an excellent material, but stiff or strong and plastic clay does not answer; it takes more time and labour than can be afforded to bring it to the proper consistency, and is very liable to crack unless it is always under water. Puddling is nothing more than lining the bottom and banks of canal or

reservoirs with this prepared clay or loam so as to enable them to hold water effectually.

81. The ordinary method resorted to in England for rendering ponds water-tight, after they have been formed in soil that will not hold water, is to line them to a thickness of from 6 inches to a foot with clay beaten up with water and wheat or rye straw *(bhusa)* by a hoe, and then to apply it as a plaster, as soon as it has become sufficiently dry to prevent its slipping or sliding down. It remains exposed to the air a few days, in order that the outer surface may become dry enough to maintain its form, and then the water is let in upon it so as to fill it, and, if this is effectively executed, the pond will generally prove water-tight. It is, however, by no means a good or effectual process unless there is the certainty of the pond always remaining equally full, and of the water not being disturbed by cattle going into it to drink, or other causes. A perfect adhesion seldom takes place between the natural soil and this lining; consequently, if it is disturbed, it will gradually give way and subside to the bottom of the reservoir, thus leaving the old surface of the ground in contact with the water. If the height of water is subject to change, a considerable portion of the top of the lining becomes exposed to the sun, and in drying cracks and opens through its whole thickness, thus permitting the water to escape when the pond becomes full again. This may be partly prevented by covering the upper part of the lining with sods or turfs of grass, but as the grass will not grow and thrive under the water, it only affords protection to the upper part.

82. A means, therefore, of using a puddle lining effectually is to enclose it within the bank in such a manner that it is supported by earth

Fig 25.



on both sides, is kept constantly moist, is never exposed to the sun or external air, or indeed to disturbance of any kind, under these conditions it will last, and be effective for ever; and such is the process that should constantly be resorted to in puddling the banks of canals. This is done by forming what is technically called a *puddle-gutter* in the bank, but the

manner in which this must be made depends upon the nature of the soil to be dealt with. Thus, supposing in the portion of canal represented in the diagram that the soil bounded by the original surface line *kl*, should be clay or any earth that is capable of retaining water, there will be no necessity for puddling any part of the work, except the newly formed bank, *k r q n*, which is wholly above the surface and may require securing. In this case, as the natural soil is good, it will only be necessary to form a puddle within the bank, the transverse section of which is shown by the lines *u z q p*, and for this purpose an excavation must be made longitudinally in that bank like a foundation or opening for building a wall; and such an excavation is called a puddle-gutter. It must extend from the top of the bank down to the natural surface, and even penetrate at least a foot or 18 inches into it, and must be kept wide enough for a man to work conveniently in it, the usual width being from 30 inches to 3 feet.

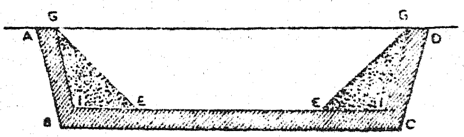
All the previously contained soil having been thrown out, the process of puddling begins. This is performed in England by a man using a scoop-tool, like a spade, and wearing a pair of very thick and strong boots made for the purpose, called puddling-boots. They come above the knee and should be impervious to water, like the high boots usually worn by fishermen. Natives of India dispense with the use of boots, puddling with their naked feet. The ground is loosened in the bottom by the scoop, but is not thrown out; that done, a pretty copious supply of water is sent into the puddle-gutter by buckets or by a temporary pump, and the workmen, by pressing down the scoop-tool, and walking backwards and forwards in the puddle-gutter, reduce all the natural soil that has been distributed into a state of very soft mud or slush, as it is called. This is done for the purpose of producing an intimate union and incorporation between the natural soil and the puddling-stuff to be afterwards added. The puddling-stuff is now brought in barrows and cast into the gutter to be treated in the same manner; a copious supply of water must constantly be given; and the more the stuff is trod and worked by the feet and scoop the more perfect the puddle will be. Nothing is found to answer the purpose so effectually as treading with the feet, and the layers of puddling-stuff should never exceed 9 inches in thickness without being trodden and worked. The step should be kept so wet that the feet sink in 8 or 9 inches at every step, and the same operation should be continued until the puddle-gutter is filled to the top, or at any rate to a greater height than that at which the water in the canal or reservoir will stand. Dry earth is then placed over the top of the puddling, to protect

it from the sun and air, while the body of it is sure to be kept moist by the water that percolates through the inner part of the bank.

When the necessity of puddling is ascertained before the work is commenced, the puddle-gutter may be formed by a less expensive method than that just described; because, instead of excavating it in the bank after it has been finished, it may be left open while the bank is forming, or, in other words, the embankment may be formed in two separate parts, as *p n q* and *k z r u;* and to prevent the gutter falling in and getting filled with the materials of the bank, the puddling process may go on, simultaneously with it, so that the whole may be kept nearly at the same level.

83. It frequently happens that the whole of a reservoir or portion of a canal may be upon sand, gravel or some soil that will not contain water in any part; and then of course, partial puddling would be ineffectual, and the whole surface must be made secure. Under such circumstances it would not even be safe to puddle the bottom and make puddle-gutters round the banks, because if the banks themselves were of porous or non-retentive materials, and they stood upon soil of the same character the water would percolate through them and escape. In such a case, therefore, the puddling must run under the foundations of the banks and rise almost perpendicularly behind them, so that the work, instead of being excavated or formed with sloping banks in the first instance, must be formed with them on a nearly vertical shape, as in the diagram. Such was the case with the large reservoirs of the West Middlesex Water

Fig. 26.



Works. They were formed wholly in open porous gravel, worked, in the first instance, into a shape like the section shown by ABCD. A bed of puddling BC was then worked over the whole bottom to a depth of 3 feet, and gravel was wheeled in to form the angular slopes EIG as soon as the bottom puddle had become sufficiently hard to bear it. Care was taken to leave the nearly vertical puddle-gutters, AGBI and GDIC, 3 feet wide between the internal slopes as they were formed and natural ground behind, and this puddle was incorporated, with that in the bottom and carried up with the banks as they proceeded, so as to make the whole perfectly water-tight, in as unpromising a piece of ground as could well have been selected.

The difficulty of obtaining good material for puddling near the place where it is wanted often proves a great drawback to the construction of canals, and increases their expense very materially. The Engineer, therefore, when he meets with it on a line ought to reserve it, if possible, and not permit it to be deposited on the banks or other places where it may be of no use, and from which perhaps it cannot be afterwards removed. It must be remembered that puddle is only of use in places where it can always be kept wet. If puddle dries it cracks and is useless.

84. The best kind of puddle for lining embankment or canals where it is not always under water, is undoubtedly what is known as dry puddle.

This is made with a little loamy soil such as would be suitable for good brick burning, and is prepared in the following manner. The soil is broken up into a powder and laid on the required site in layers not exceeding three inches each in thickness then rammed tightly with heavy rammers. Only just enough moisture should be added to enable the earth to be tightly rammed.

Earth which has just a little moisture in it is the easiest to work up, as it can be broken up finely and rammed tight without the admixture of more water. When water has to be added, an ordinary watering-can may be used with a rose on the spout, such as is used for gardening purposes. It is often difficult to obtain water at site in India, so dry puddle is generally easier to make than wet puddle, and for most purposes it is also superior.

85. **Puddle cores.**—With reference to the use of puddle, Colonel Rundall remarks :—

"In constructing reservoir embankments it has never been the practice of native Engineers to use puddle cores. The soil of which the embankment is composed being carried on men's heads, is necessarily deposited in small quantities at a time, and is so thoroughly trodden down by the passage of the labourers over it that it gets very fairly consolidated, and as, in the case of large banks, the time occupied in their construction may extend over two or three years, the earthwork has the benefit of exposure to the rains, which cause it to take up its settlement, and to become much more campact than it would otherwise be. My own opinion is decidedly adverse to the use of puddle cores (Plate II., Fig. 1) as adopted in England, for one reason—that a bank composed of two different descriptions of earth is much more likely to settle unequally than if the whole is made of one kind of material. The one essential in

the construction of large earthen banks is to use, as nearly as possible, a homogeneous material so as to ensure the mass settling evenly. I do not remember to have seen an instance of a bank, after being once thoroughly consolidated, breaching from simple hydrostratic pressure, the usual cause of tanks breaching being the overtopping of the embankment either from insufficiency of escape or from want of due attention in preserving the level of its crest. Injuries do sometimes occur in small banks from the borings of rats and other vermin during the dry season, when the tank or canal is empty. There are of course soils so porous that they are unable to sustain any pressure of water without leaking, which must, therefore, in course of time produce such a settlement of the bank as would bring its crest below the water level, and thus ensure its destruction. But in such a case my own opinion and experience would lead me to place a clay lining on the interior slope, in preference to adopting a puddle core, for this obvious reason — that the object of an Engineer is, or should be, not to let any water at all find its way into the mass of the bank, rather than to try and stop its proceeding from one side to the other which is apparently the use of a puddle core. It is obvious that, if the material composing a reservior bank is not sufficiently water-tight to prevent filtration, then the mass on the interior side of the core will in time get thoroughly saturated, and there will consequently be only half the section of the embankment and the puddle core left to sustain the hydrostatic pressure brought against it. That section may or may not be sufficient for the purpose. If it be not so, then the bank must give way in spite of the core, and if it be sufficient then it seems clear that the interior prism of the bank is not wanted for sustaining the pressure and so the conditions of the bank are actually reduced to that of a prism with a lining of puddle clay on the interior face. Better, therefore, to adopt the expedient at once of lining the interior slope in cases where the quality of the soil renders it a necessity. It is, however, also urged that in cases of porous soils it is necessary to carry the puddle wall down to a water-tight stratum, in order to prevent the water percolating through the soil and under the seat of the embankment; but supposing such ever to be necessary, it would, in my opinion, be better to place the puddle trench at the toe of the interior slope, and so effectually prevent the possibility of any water finding its way into any part of the embankment seat. (See Plate II., Fig 2.)

"But though I consider puddle linings need only be resorted to under special circumstances, yet I would in no case omit the protection which a revetment affords to the preservationof the interior slope. In all cases

where there is a greater depth of water than 10 feet against a bank, a loose stone revetment or lining should be built; and in all shallower tanks, revetment made of grass rolls. In many cases the natives of India have planted the palmyra tree on the interior slope. These afford great protection, acting as a breakwater against the waves, while at the same time they are very profitable trees, their juice, leaves, bark, fruit, and fibre being always turned to account for various purposes. From well-grown trees, also, joists and rafters are obtainable, the hardness of the wood rendering it impermeable to the attack of the white ant, the great enemy of the Engineer in India."

The remarks made by Colonel Rundall many years ago are unquestionably sound and are accepted by most Engineers. On the other hand, puddle cores are still advocated by a few Engineers. In some cases a puddle or a masonry core wall is most useful. Where embankments are constructed on rock or on ground where there is rock at the short distance below the surface, a small masonry core wall built on the rock and run for a few feet into the new bank is most useful in stopping the creep of water. Small puddle or masonry core walls are also useful where an embankment is made on very porous soil with an impervious stratum or with rock lower down, or when the ground below the embankment has a sand or *bajri* strata a few feet below ground level. In such cases the masonry or puddle core walls which are only carried a few feet into the new embankment cut off the creep of the water along the rock surface, or the water which filters through the pervious soil or strata, and in no way interfere with the uniformity of the superstructure.

86. In plate II are shown several sections of embankments for holding up water, but there is a great difference of opinion among Engineers regarding the best dimensions for the top widths, the side slopes and the free board between the high flood level and the top of the bank. A small top width may be theoretically sound but it is not possible always to maintain the bank to the exact section, and an excessive rather than a tight width is strongly recommended. A broad top is more useful as a roadway, and the damage done by cattle and a heavy rainfall can be repaired before the bank becomes dangerous. Some engineers make flat upstream slopes, and steep downstream slopes. They contend that the upstream slope becomes most saturated and is more likely to slip than the downstream slope. This is true, but when saturated earth is liable to slip on the upstream, it means that a great top width or very easy downstream slopes must be given, otherwise the line of saturation will reach the downstream slope and this will slide. On the other hand,

if the earth is stable then the flat upstream slope is unnecessary. The most economical section and one which has been built with success in many places, is a steep upstream slope of 2 or 3 to 1 which should be pitched with dry stone pitching to prevent wave action. The top width and the downstream slope should be adjusted so that the perpendicular from the line of saturation, or as it is commonly called, the hydraulic gradient (assumed at 4 to 1 which is a very safe value for all ordinary soils) may not be less than 8′ from the outer slope at the toe of the bank.

The higher the bank the greater should be the freeboard and the top width and the greater should be the perpendicular distance between the outer slope and hydraulic gradient.

A dry stone toe should always be given to high banks for it acts as a drain and buttress and will prevent many a slip.

Berms are sometimes given on the downstream slopes to provide the necessary stability, but though they may be economical they are not recommended. It is better to increase the top width and flatten the outer slopes, as they are easier to drain and cost less in repairs.

SECTIONS OF RESERVOIR BANKS.

Fig. 1.

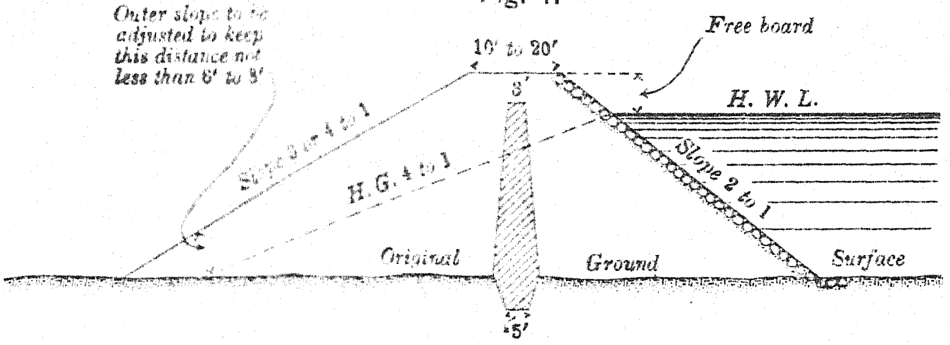


Fig. 2.

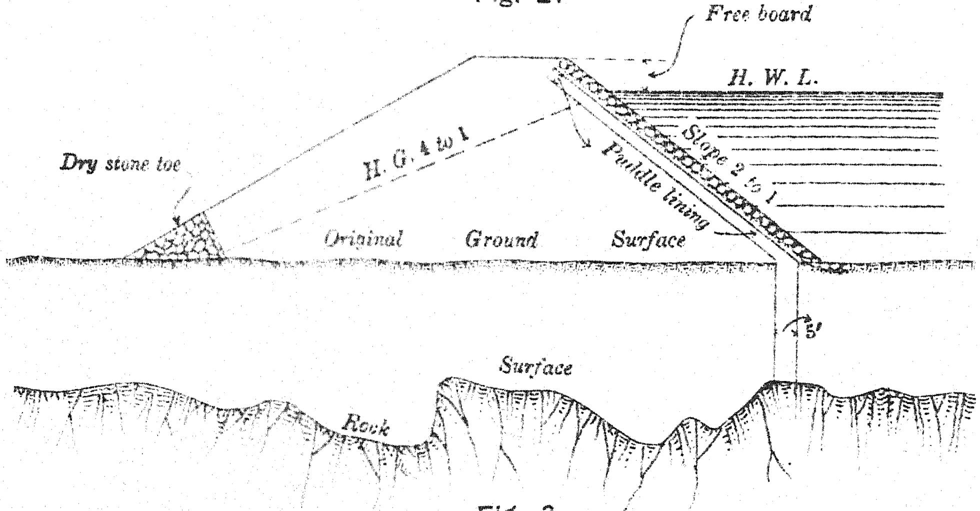
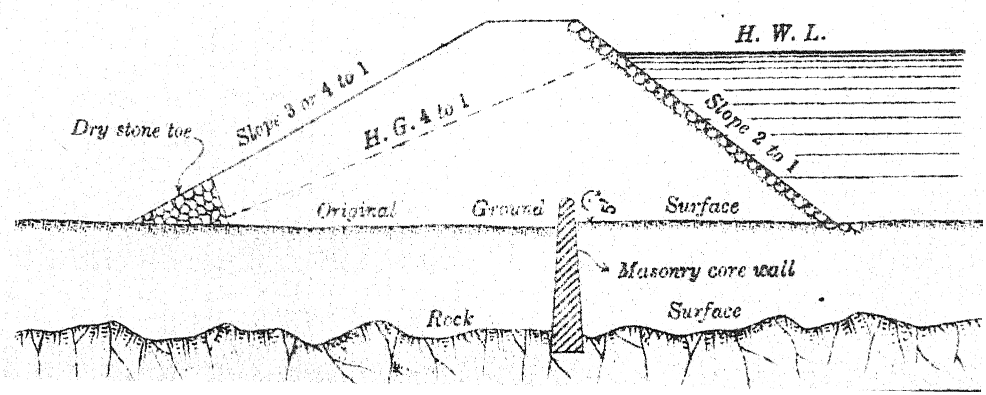


Fig. 3.



CHAPTER VI.

MAINTENANCE OF EARTHWORK.

87. **Maintenance.**—The careful maintenance of earthwork, both during construction and when the work is finished, is most important, and especially in all high embankments, or banks which have to hold up water.

Unless precautions are taken great damage and loss may result during the rainy season, and unless all earthwork banks are kept in good order, they will rapidly deteriorate and may soon become dangerous.

During the construction of a bank precautions should be taken to ensure uniform consolidation, and also to prevent large portions of the work being washed away during the rainy season. In a cutting the adjacent drainage must be considered for if it is not diverted it may enter the cutting and scour out the slopes, and deposit earth in the bottom or even scour out the bottom of the cutting. It may also fill it with water if the ends are blocked and so stop all work for months.

In nearly every case the Engineer should consider the drainage both on embankments and in cuttings during and after the construction of the work.

In a high bank any damage which has taken place during the rains should be rectified as soon as possible, otherwise the damage will increase, and if left till the bank approaches completion, new and old portions will not unite properly, slips will take place and the bank will be a source of trouble for years.

For several years after high banks are constructed the repairs will be considerable, and a good bank will never be made unless repairs are promptly and thoroughly carried out.

In paragraph 72 attention has already been called to the question of settlement; it is again mentioned here as it is so often lost sight of in repair work. One generally finds that holes or scour which have taken place are refilled with earth to the same level as the rest of the bank which has already either fully or partially settled, and no allowance is made in the new work for settlement. Immediately this new earth is saturated with water it subsides and a hollow is formed, which results in further damage from the drainage which collects after the next shower.

88. **Slips.**—Excess of moisture is the chief cause of the instability of all earths. The drainage or diversion of water from land liable to slip is therefore the first point to which the attention of the Engineer should be directed.

Sand, gravel, and generally porous soils which do not naturally retain moisture, are fairly stable, provided the moisture has a free outlet; but the subsoil water is sometimes retained by an impervious surface of clay or a masonry retaining wall unprovided with weepers, and then slips follow as a natural consequence after heavy falls of rain.

The worst descriptions of soil are some kinds of clay and loose rock or shale, which, by the admixture of surface drainage and of spring water, get into a semi-fluid state and retain moisture.

The drainage of such soils is extremely difficult and slips are of constant occurrence.

Stiff clays and soil known as black cotton, are most unsatisfactory for high banks. They are generally very hard to dig, and when dry, form into large clods. These soils are greatly affected by water and air, for they expand when moisture is added and then become almost impermeable, but contract and crack badly when dry, and through these cracks water percolates.

Canal banks or water embankments of this soil become saturated, and during a closure or when the water falls low, cracks are certain to occur. Consequently when the water level rises again there will be breaches, unless the banks are carefully watched. Whenever it is possible sand or silt should be mixed with these soils to reduce the cracking, but silty water is seldom available, and the only method of avoiding breaches is by raising water gradually, and so saturating the bank and closing the holes above the water level. Gangs of men should also watch the banks and be ready to work up and block on the inside of the bank any leakage which may occur.

Clay and black cotton soils should be avoided, but when they are used to hold up water they should be encased with some light soil or débris. In this manner atmospheric action will be minimised if not prevented.

89. Stratified rocks, with the dip towards the cutting, are liable to slip, especially if there is a stratum of clay or of any other material between the various strata of rock through which surface drainage or spring water may filter.

Extensive slips in earthwork seldom occur during excavation or for a short time after the completion of a cutting; on the other hand, movement in an embankment frequently happens during deposition. In the case of an embankment time may cause the earth to become consolidated, but in a cutting the disintegrating and disturbing process, and the combined action of air and water percolating until they force forward the earth, are usually gradual in their operation, and often require a year or two to

cause a state of instability; in fact the history of slips, in soils whose condition is very readily changed by water, indicates that serious movement in cuttings does not generally occur until a cycle or two of the seasons has elapsed, during which period meteorological influences, aided by vibration and other deteriorating operations, are slowly and regularly proceeding; until at length such a change in the general condition is caused, that a slip happens, apparently from some sudden agency, whereas the stability of the earth has been gradually and surely wasting away for a long time: hence the importance of continual careful observation in cuttings even of moderate depth in doubtful soil.

90. **Drainage of embankments and cuttings.**—Rain will percolate through any open soil until it meets an impervious stratum, or a place already in a state of saturation, when the water must either flow away or the level of saturation must gradually rise.

The aim of any drainage operations to prevent slips in earthwork is therefore to search for the source of the water supply, and to tap and gently conduct it away; also to prevent rain or spring water percolating, accumulating or being confined within the slopes of a cutting or embankment, which may thereby be reduced to a pulpy condition. The drainage of all such accumulations is most important, as is also the lessening of the percolation of rain and surface waters. To reduce the volume of the percolating water is the object to be attained and then evaporation, filtration, and time will gradually convert the earth to the desired consistency.

91. The action of slips seems to commence at the toe, which, if protected, often prevents further damage. The time therefore to build up the revetment wall is as soon as possible after the cutting is made. They should be put in wherever there is the slightest appearance of rotten soil, or if the strata slope down towards the road. It is not economical to wait till the slip commences, for when earth is once on the move, there is no saying where it may stop or what damage may be done, or how long the road or channel may be blocked.

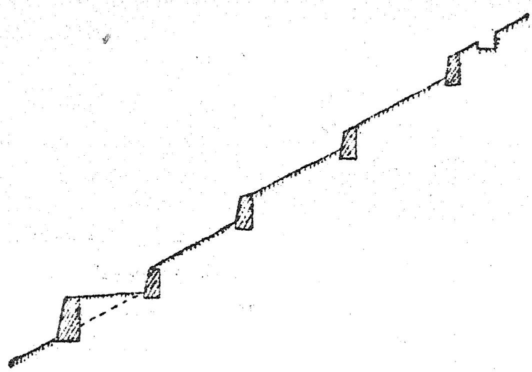
92. Revetment walls are often built 10 to 15 feet high, which is a great mistake, for the section of such a wall, to be of any use, would have to be very thick and hence would be difficult to put into a cutting of rotten soil. Such walls should not be more than from 2 to 4 feet high and from 3 to 4 feet thick, of dry rubble masonry. The depth of foundations should vary in proportion to the scour likely to occur along the face of the wall, from the side drain or from any other cause.

When no such action is to be feared, a depth of from 1 to 2 feet should be sufficient.

The power these walls have in staying the movement of a cutting is marvellous. A solid dry stone toe is frequently necessary for high embankments which hold up water. These act as drains and also as a buttress and prevent slips which would otherwise occur. Many Engineers for economy's sake are too fond of steep slopes both on banks and in cuttings, and before other precautions can be taken to stop slips the most satisfactory treatment will frequently be to flatten out the slopes.

93. One method that has been found successful is to build dry rubble walls across the slip about 3 feet high.

Fig. 27



The surface can also be drained by digging ditches about 3 feet deep vertically down the face of the slip, and filling them in with brushwood and loose stones; these, however, get choked in some kinds of soil. In such places open saucer surface drains have been found more efficient; these drains should follow the natural lines of flow of the surface drainage (which are generally clearly indicated), and should be paved with any material available to prevent scour, the sides being low enough to admit the surface water. The surface should also be planted with grass or brushwood. This is not an easy process, because grass will not grow readily on freshly exposed earth. It is therefore necessary by local examination of old slips and from inquiries in the locality, to find out the kind of plants that will grow on the kind of soil of which the slip is composed. Some good soil may also have to be put round the roots of the new plants. This should be done in the cold weather, in order that the plants may take root before the rains set in, and the whole should be kept watered as long as may be necessary.

No surface covering can be better than grass. This should be laid on in sods, not less than 6 inches thick, well packed together, bedded into the bank and watered till it begins to grow. It is essential that the sods should not be less than 6 inches deep. It is usual to cut nice looking turf, from 2 to 3 inches thick; this has not sufficient root, and will die on the first exposure to heat and will probably be quite useless by the time the rains come on.

Turf is however seldom available in India, so the surface must generally be planted with those grasses and shrubs which grow on such soils.

Another method for protection similar to the cross walls above described is to dig out horizontal ditches from 1 to 1½ feet deep across the slip, and drive in stakes about 5 feet long at intervals of about a foot apart and allow them to project a foot above the face of the slip; hurdle work is then wattled in round these stakes and the earth is thrown again into the ditch.

These hurdles act much in the same way as the walls, and are useful under certain circumstances and where no stones are to be had. If the wattling is made of boughs of plants that will grow from cuttings on the soil of which the slip is composed, they will often take root and form a very strong barrier across the slip. Some people advocate the planting of trees on these slopes, but the trees are very liable to be blown down and then they are the cause of considerable trouble. The surface drainage of the slip must of course be carried out in every way that the local circumstances show to be advisable, and all surface or spring water likely to affect the slip should, as far as possible, be diverted.

Experience alone will show the best way to treat slips on the different kinds of soil on which they occur, and the Engineer must use his ingenuity according to the local conditions in each case.

94. When a channel is made through rotten soil it is frequently necessary to line the bed and sides with closely packed stones laid dry. If this is not done the bed is liable to scour and when this occurs the sides are liable to slide forward. When such scour takes place and the sides fall in, the loose soil is quickly washed away. Then the bed is cut still lower and more of the sides fall in; after this process has gone on for some time the hillside may begin to move. An axiom to be observed in all work in bad soil is that you should never allow water to collect; that is you must then distribute it in every possible way. Whenever a strong stream collects, damage to banks may be expected. Drainage should be carried over the strongest available soil. Thus, if the discharge from a road scupper is cutting away the hillside, it will be found more economical to change the side of the scupper than to maintain the weak outlet.

CHAPTER VII.

EARTHWORK ON HILL ROADS.

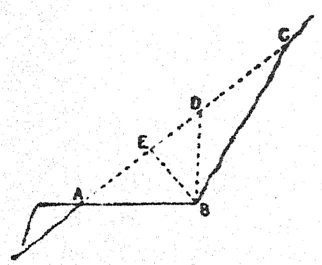
Notes taken by COLONEL F. D. M. BROWN.

95. The following notes made by me when Superintending Engineer, may be found useful to students if employed on hill roads, and are therefore attached to the Earthwork Manual. I am indebted to Mr. L. B. Simeon, who was the Executive Engineer on the construction of the Ranibagh and Ranikhet cart-road, for much of the information given in these notes: his inventive genius was always on the look out for improvements whilst his forethought and methodical arrangements contributed to the quick and economical construction of the road.

96. **Measurements of work.**—In making a hill road the cutting should be first made with a vertical face. This section should only be paid for at the rate for cutting; it should be specified in the contract bond that any cutting beyond the vertical would only be paid for at the lower rate for removing slips. It is impossible to know at what slope the hill side will stand; it will often stand vertical, when extra cutting would be waste of money; and if it will not, by letting the bank take its natural slope, the removal of the earth that slips will cost less than digging it out in the first instance.

Measurement of work on a hill road cutting.

Fig 28.



$$\text{Area } ABC = \frac{AC \times EB}{2}.$$

$$,, \quad ABD = \frac{AB \times BD}{2}.$$

$$,, \quad CDB = ABC - ABD.$$

To obtain these measurements easily get a piece of strong well stretched thin rope, about $\frac{1}{4}$ inch diameter, and longer than any possible measurement of AC. Take a point E, near one end of the rope, as the zero point, and mark the rope off in feet from E, towards both A and C. Every 5 feet being distinguished by a blue mark and every 10 feet by a bright red mark, so as easily to read the lengths. Attach also the zero of a 50-foot tape at the point E.

(1) Now place one man at A, one at C, and one at B. The men at A and C will move the rope up and down till the angle AEB—formed with

the tape—is a right angle. This can be judged near enough by the eye—also when EB has the shortest reading. Then read and note in your book the measurements AE, EC, and EB. If C is too high up to read with the naked eye, it can be read with binoculars; the parts of a foot can be judged by the eye to the nearest quarter of a foot.

(2) Now pull the rope down from E to A; read off and note the distance AB on the tape.

(3) Now pull the rope towards C till the point E is at D, and the tape BD makes DBA a right angle with the road BA, which can also be judged by the eye. Then read off BD on the tape, and note it with the previous measurements in the following form.

The measurements of sections along the road should be taken at equal intervals, say 20 feet, and the mean of these taken as the mean section of each chain. Sections at equal intervals will generally give a very accurate measurement, taken one with the other; and in the event of it being necessary, the measurements can always be accurately checked at each point, which cannot be done any other way, owing to the sections rarely being the same at any two points. You will thus prevent all disputes or attempts at false measurements by either contractors or subordinates.

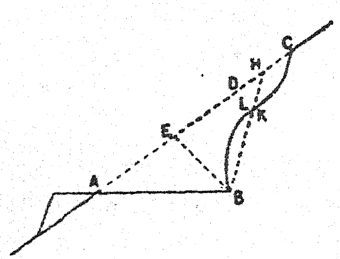
Form of Measurement book.

No of chain.	Distance in feet.	H.	P.	W.	V.	$\frac{H \times P}{2}$	$\frac{W \times V}{2}$	Area per chain of ACB= $\frac{x}{n} \times 100$.	Area per chain of ADB= $\frac{y}{n} \times 100$	Area per chain of CDB= $\frac{x-y}{n} \times 100$.
1	0 20 40 60 80 100	AE+EC	EB	AB	BD	$\frac{AC \times EB}{2}$	$\frac{AB \times BD}{2}$			
Per chain, Total cubic feet						x	y	$\frac{x}{n} \times 100$	$\frac{y}{n} \times 100$.	$\frac{x-y}{n} \times 100$.
2	0 10 &c.									

N. B.—$\frac{x}{n}, \frac{y}{n}$ where x and y represent the totals of all the sections in one chain, and n the number of sections taken in that chain.

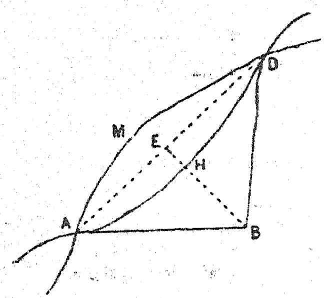
In measuring the slipped portion DBC excess measurements must be guarded against, as the upper portion only may have slipped; and in that case some intermediate point H (Fig. 29) must be selected, so that the excess LBK may compensate for the unmeasured slip CHK; the length AH will be entered in the measurement book instead of AC.

Fig. 29.



If the hill side has a section DHA (Fig. 30), the formula $\frac{AB \times BD}{2}$ would give excess measurements; and if the section was DMA, the formula would give short measurements. When giving out work, therefore, each chain should be given a factor which should be entered in the column under the chain to which it refers; and this factor should be used when calculating the areas x and y of that chain. For convenience this factor should vary by tenths. Thus, the area of BDHA would be nearer $\frac{3 \times AB \times BD}{10}$ than it is to $\frac{AB \times DB}{2}$. Therefore $\frac{8}{10}$ would be put in the first column under the chain to which it referred, and used in both triangles instead of the factor $\frac{1}{2}$. Similarly, if the hill side had the form DMA, the factor would have to be increased, and $\frac{7}{10}$ would give more correct measurement. The factor $\frac{7}{10}$ would therefore be entered in the first column of the chain to which it referred, which would indicate that in calculating the triangles the formula $\frac{7HP}{10}$ and $\frac{7WV}{10}$ would be used instead of $\frac{HP}{2}$ and $\frac{WV}{2}$. By working out a few sections in detail, the Engineer would be in a position to fix the factor pretty accurately. It is by giving fair measurements that contractors take kindly to the work and do not dispute accounts. Without some such rule there would be a rush of contractors for section DHA, while without apparent cause they would raise the rate on section DMA. And this would eventually tend to enhanced rates. A note of the factor decided upon could conveniently be made in column 1 of the measurement book, below the chain to which it referred, as also the rate agreed upon for that chain.

Fig. 30.



97. **Lining out the road.**—Before commencing work the exact line of road should be carefully marked out by a pathway, and at every chain

an unremovable—say masonry—bench-mark built at A (Fig. 29) on this pathway, behind which a bank should be left to protect the bench-mark which indicates the outer edge of the cutting. Strong pegs should be driven at intervals between the chains on the outer edge of the pathway, where the sections are to be measured, and similar mounds left behind them for their protection when excavation commences. These should on no account be moved until the work has been measured up and the bills for the first vertical cutting finally settled. Otherwise it is often impossible to tell exactly where the cutting commences and gives rise to disputes in settling the accounts.

98. **Giving out work.**—It is convenient to give out the work in five chain lengths; but on no account should ground be broken throughout, but only over one chain; and the second chain should not be commenced till the first chain is nearly finished and the gangs unemployed. Unless this is carefully guarded against contractors will open work throughout the five chains, to give them a claim to the piece; will remove all the soft upper soil and then begin to dispute the rate, and ask payment for all at the rate of the harder stuff exposed below.

99. **Rates.**—There should be several rates for the work made on some fixed and recognised scale, according to the nature of the soil generally found in that part of the country. The rate from this scale should be agreed to chain by chain, as the ground is opened out; the terms of the contract being, that if the contractor cannot agree to terms, the officer in charge of the work has power to refuse him all further work on the still untouched chains of his contract. The contractor should also be bound by a heavy penalty not to commence work on a second chain without a work order in writing.

100. **Estimating the quantity and laying outside widths of a hill road.**—Mr. Simeon was of opinion that as a rule it is more economical to cut the full width of road at once out of the hill side and not trust to a part of the width being formed by the spoil. That the expense of cutting back, if the spoil does not stand, and the expensive walling, rendered necessary to complete the width, both delays the making, and adds to the cost of the road. The last section of the Ranibagh and Ranikhet cart-road was therefore cut to the full width, and he found a great saving thereby.

101. **Cutting at once to formation level.**—After the road has been carefully laid out—as above explained—and the work has been properly given out to contractors, it is found that they can work properly to the pegs. It is therefore not economical to have the cutting done to 6 inches

or 1 foot above gradient level, as is the usual practice the after-dressing is difficult and only taken at enhanced rates. The contractor should be bound to dress and complete his section to the pegs given to him which he can do very well.

102. **Cross section of hill card-roads.**—From the long experience I have had in the maintenance of hill cart-roads, I consider the best cross section for a hill cart-road to be one that has the entire slope outwards, **with no inside drain.* This section is always adopted on bridle roads in the hills, the cost of maintenance of which is trifling; whilst for a cart-road the inside slope or a hog-backed section is always recommended. A hill cart-road is only about 10 feet wider than a bridle road, and the extra rainfall to be discharged for this small portion—provided it has an immediate outlet—will be found on calculation to be quite insignificant. Long experience on hill bridle roads and a few years' experimenting on the Naini Tal tonga road, where the rainfall is excessive and the soil very bad, has proved to me that a hill road with an entirely outward slope and no inside drain is more easily and more economically maintained than with any other section. A side drain may be necessary in places to lead away a spring from a soft part of the road, etc., but these are only the exceptions which pertain to the general engineering of the road.

A slope entirely inwards or with a hog-backed section is especially unsuitable where the sides are liable to slip. The smallest slip of a few buckets full of earth—or even the collection of a few leaves which allow the silt to accumulate—will choke the inside drain, when the accumulated water will course down the road, causing much injury to the surface, and discharge itself over the outer edge in a strong stream, often at a weak place, which may cut away the bank or destroy a retaining wall. Similar damage may be done when a scupper gets choked.

The inside drain is also contrary to one of the first principles of hill engineering, which is, that water should not be allowed to accumulate; except of course in the main streams. As a matter of fact maintenance gangs invariably seek shelter during a heavy fall of rain, and it is during the actual falling of the rain that the chief damage is done to a road. Ten minutes after the rain has stopped, the side drains are practically dry. The best arrangements therefore that can keep the road properly drained during heavy rainfall should be adopted. The outside slope has not in practice been found inconvenient for fast traffic. The tongas travel downhill on the Naini Tal road at 10 and 11 miles an hour, without more

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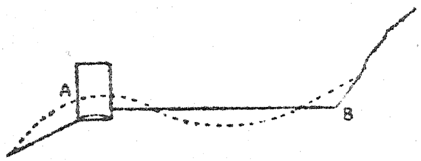
*All engineers do not agree with these remarks.

inconvenience on the miles with the outward slope than on the miles with the hog-backed section. Any danger that may be anticipated from the centrifugal force at salient angles could not affect a vehicle until it was on the outside half of the road; and then it would be immaterial whether the other (inner half) had a slope upwards or downwards. The drivers have invariably told me that they prefer the outward slope, as they have only to look out for danger on one side, whereas on the old section they had also to take care to avoid the inside drain.

An outside slope of 1 in 20 has been found in practice to be the most suitable, but with a small rainfall or a slight gradient it may be a little less.

When a road is made with an outside slope the following precautions have to be borne in mind for its proper maintenance (*Fig* 31):—

Fig 31.



(1) That the outlet at A is low enough to discharge the road drainage freely. This is often blocked by—

(*a*) The road wearing down in the centre.

(*b*) When slips are cleared away, a lot of the spoil is left at the outlet, and thus a bank is formed at A (as shown in dotted lines), which obstructs the free flow of the road drainage.

(2) The earth from slips should be cleared clean away to the full width of the road, and not left banked up against the side by a lazy gang, as the width of the road is thereby reduced.

When these precautions are not observed, the road may assume the section shown by dotted lines, when the centre of the road would become a water-course and be thereby destroyed.

The outlet A, mentioned above, refers to the 3 feet intervals left in the parapet walls to pass the surface drainage. The parapet walls being built in lengths of 10 feet with 3 feet intervals. By this arrangement $\frac{3}{13}$th of the parapet walling is saved, whilst they are equally efficacious as an outside fence. Or the parapets may be built in 7 feet lengths with 2 feet openings.

Another advantage of the outside slope is that the road is widened by the 2 feet required for the inside drain; or the width of the cutting may be reduced 2 feet in first construction. As this is the inside 2 feet, where the heaviest digging is required, the saving in first construction would be great.

Scuppers at every three or four hundred feet also become unnecessary, as also their expensive maintenance.

Should the soil be strong and the rainfall moderate, there is no objection —except so far as the great increase of cost is concerned—to making the road with a hogged back and with an inside drain and scuppers, if this section is preferred, but with an excessive rainfall, or in bad soil liable to slip or to be washed away, there is no question but that—from an engineering point of view—the outside slope should be adopted; and I am very sure if the engineer has to maintain any hill road after he has made it, he will for ever be thankful if he has given it an outside slope.

CHAPTER VIII.

EARTHWORK FOR CANAL DISTRIBUTARIES.

103. Distributaries are canal channels of moderate discharging capacity from which village water-courses are directly supplied with water; as a rule they follow a tortuous course through cultivated or good culturable land.

As distributaries are constructed for the improvement of the land lying close to their banks, as well as for the more distant parts of the tract of country they command, it is necessary, to avoid, as far as possible, the damage which would be caused by deep borrow pits or heavy spoil banks.

104. Unless circumstances demand a special course, it is usual to vary the width of the banks of a distributary in proportion to the bed width of the channel. Thus a large major line will require a cart road along one bank and a riding path on the other. Lines carrying moderate discharges always have both banks at least wide enough for riding, while minor lines have paths along which a horse can go at a walk only. A riding path for inspection purposes is sometimes provided on the country level outside the banks and this course is also followed for roadways on large channels where dips in the water shed necessitate a high embankment along which it would be expensive to make a road way.

It is also usual to increase both the height of bank above the channel water surface and the width in proportion to the discharge, in order to diminish the chances of a breach of the banks. A breach in a small minor channel is easily closed and can do but little damage to the surrounding country; on a major line the case is quite different for not only may great loss be caused to cultivators, but the large area which is certain to be flooded, will render the provision of earth for repairs of the breach both difficult and expensive.

105. Now bearing in mind this proportion of the dimensions of banks to channel, it will be found that, if the water surface in the distributary is kept above the ground level (as it should be kept to fulfil properly the requirements of irrigation from a distributary on the watershed), the inside excavation should supply just about the proper quantity of earth for the banks if the channel is well proportioned for hydraulic purposes.

The bed line can be kept fairly parallel to the ground surface by making several low, instead of a few high, masonry falls to provide for that slope in the country which is in excess of the gradient required for the distributary. It is therefore in the power of the careful designer to fix a depth of excavation for each change of cross section in the channel, which will provide as nearly as possible the proper quantity of earth to make the banks. In the Tabular Earthwork form accompanying this note, this depth of excavation is termed the "Economical digging," and it is advisable to calculate it out for each change of cross section before laying down the bed line on the longitudinal working section.

It is not possible with an uneven ground surface (and all surface contours undulate more or less) to adhere strictly to a particular depth of excavation, but a knowledge of the economical digging will help the engineer materially in adjusting the bed line to the best position, and the time and care bestowed will be well rewarded by economy in construction, neatness of the completed work, and the knowledge that no more culturable land has been injured than was absolutely necessary.

106. In order to avoid high spoil banks, distributaries should be aligned with great care in undulating ground. Before the section is plotted on paper it is almost impossible for the engineer laying down the direction to tell whether he is taking the line too high or not; a trial section would, of course, remove this difficulty; but the best procedure is for the engineer, in the first instance, to lay down his line strictly on the watershed, and after he has plotted it in this position, and laid down the proposed bed, to remove it from high elevation or *kheras* to a contour round them, which will give economical digging. It should be remembered that as the high elevation cannot possibly be irrigated directly from the distributary, there is no possible object in plunging into deep excavation, which is certain to be not only expensive to dig but very difficult to maintain.

When removed to a side contour in elevated country the channel will be in sidelong ground, and the high side must be protected by the construction of a catch-water drain, this precaution should never be omitted even when the side slope is very slight.

107. Distributary channels in earth are generally dug of a trapezoidal section with side slopes 1 to 1.

108. When the channel has been running for some time, it will be found that the 1 to 1 inside slope will be eroded at the base, and grass growing near the surface level will catch silt and alter the section to a form approximating to a ½ to 1 slope; when this occurs it is usual to trim

PLATE III.

Fig. 1.

SECTION OF A FASCINE REVETMENT TO WITHSTAND SCOUR.

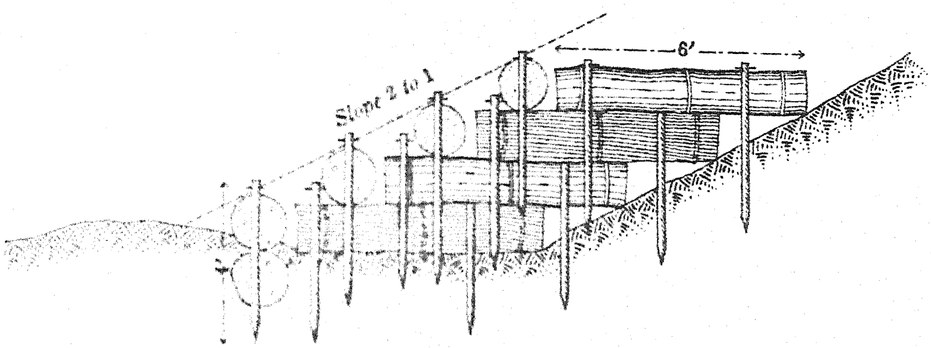


Fig. 2.

SECTION OF STONE PITCHING ON FACE OF EMBANKMENT OR CANAL.

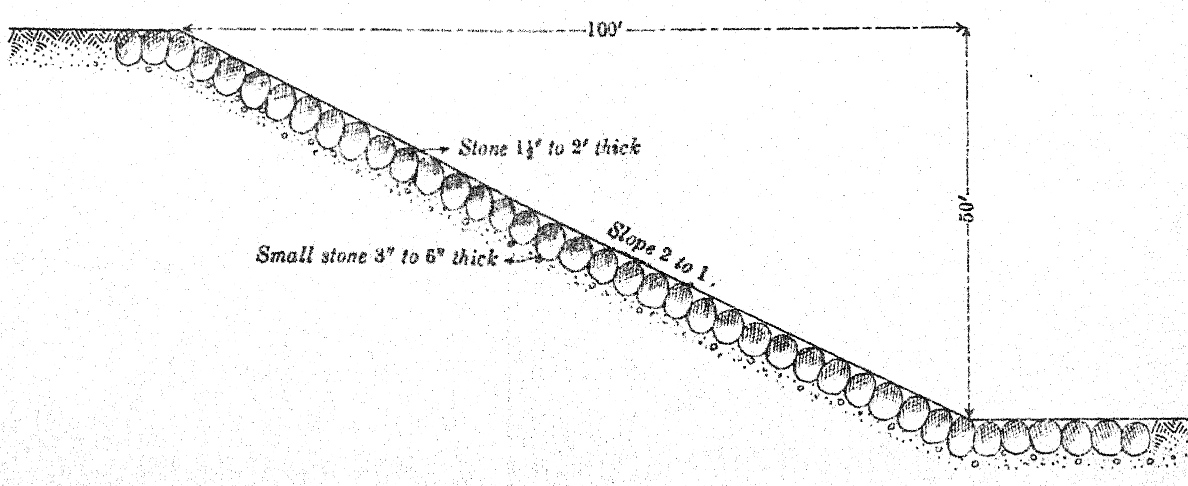


Photo. Zinco., June, 1925.—No. 835-19-1500

PLATE IV.

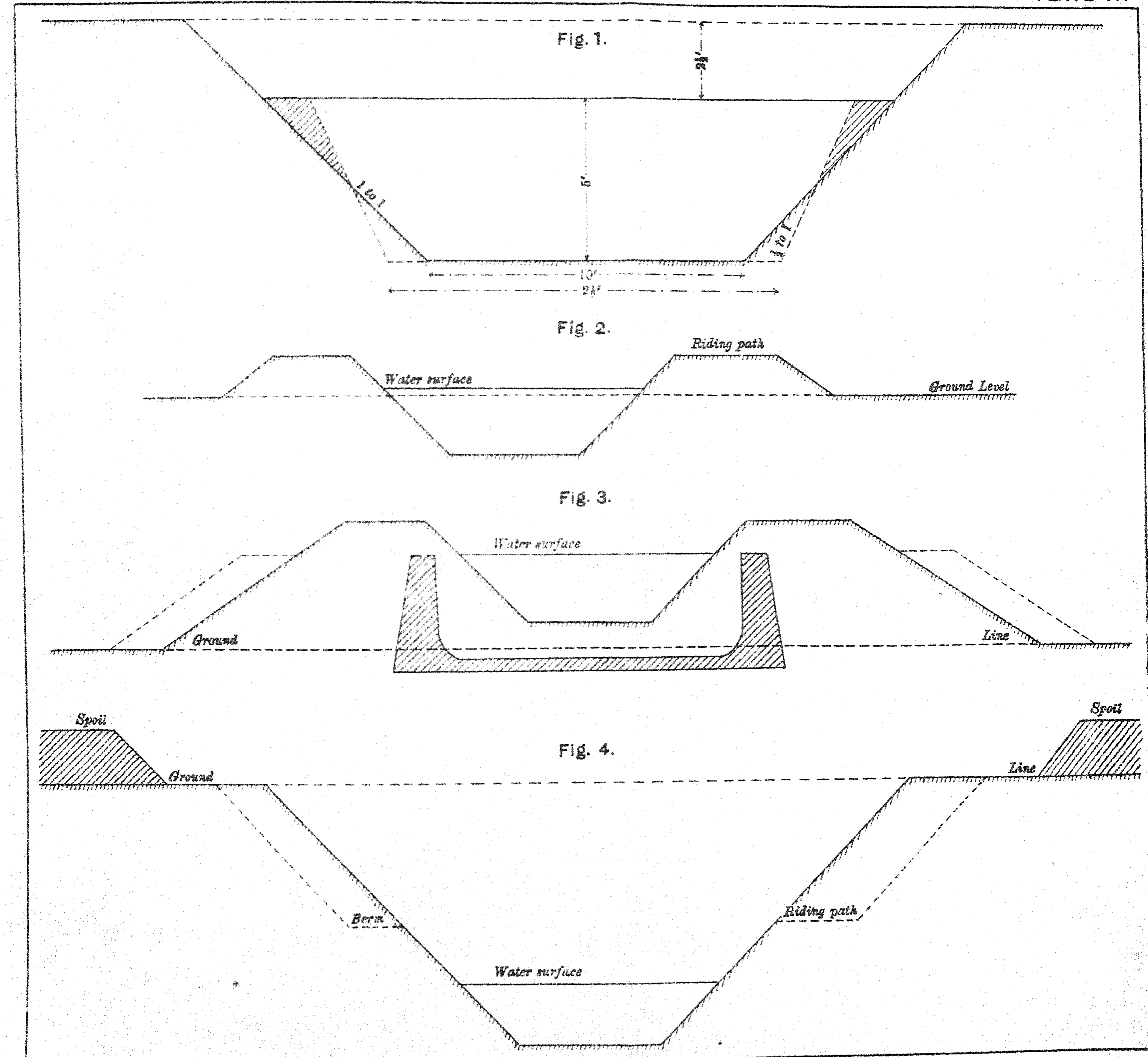


Photo. Zinco. October, 1925.—No. 835-18.

the sides to the ½ to 1 slope, increasing the bed width so as to give a wet area equal to that originally provided.

Fig 1, *Plate* IV shows the original section to which the distributary is dug, and by dotted lines the ultimate section which it will assume after running for some time; the shaded portions are the silt berms. It might appear simpler to dig to ½ to 1 in the first instance, but few soils would stand at this slope in excavation, and none in embankment, until consolidated by the action of silt-laden water.

109. *Figs.* 2, 3, 4, 5 show different types of distributary cross sections. The advantage of economical digging is noticeable in *Fig.* 2, and the great expense of heavy embankments and deep channels is shown in Figs. 3 and 4.

In heavy embankment outside berms (*Fig.* 3, dotted lines) are often necessary and to make them is cheaper than to increase the whole width of the bank, but this plan has its disadvantages too.

The top widths shown in the diagrams are only suitable for good earth and a moderate rainfall; for sandy soils, liable to weather or cut into ravines, wider banks are necessitated.

The outside slopes are shown as 1½ to 1 and this is the steepest slope allowable; 2 to 1, or even flatter slopes, are often found necessary.

In deep cutting berms are required to preserve the slopes from injury; they are liable to fall in from under-cutting by the water running in the channel, to be cut into ravines by the direct action of the rainfall, and to slip by being softened and over-weighted by percolation from the rainfall on the adjoining country: berms partially prevent these accidents and facilitate inspections and repairs.

110. It is difficult to dispose of the spoil from deep cuttings without throwing land out of cultivation. The best plan is to take up the area of land required as a temporary measure, and spread the spoil over it in layers from 1 to 2 feet thick. The weathering effects of the atmosphere and the rainfall will render the spoil culturable in a couple of years when the land can be returned to the owners.

A berm from 3 to 6 feet wide should be left between the toe of the spoil bank and the edge of the channel; the spoil should be dressed so as to carry the drainage away from the channel, and openings should be made at short intervals to allow the drainage of the berm to pass away through the spoil.

Spoil banks present a much neater appearance when dressed off with a fixed height and width varying with the quantity of earth.

111. Many experienced canal engineers recommend the system of throwing back the banks of distributary channels so as to leave a space on either side for the deposits of thick silt berms. (See *Fig.* 6, *Plate* V). This is an excellent procedure where the percolation is likely to be great, because the clay silt deposit which is slowly thrown down by the canal water is much more watertight and compact than the natural soil; there are, however, objections to the practice. The supply in the distributary cannot be kept to its calculated level owing to the extra width of channel, and the temporary means, which must be used to artificially raise it, cause weed growth. It often takes years for the deposit to accumulate and the original design is liable to be lost sight of.

Other designers allow a narrow berm between the channel excavated in the natural soil and the artifical banks (*Fig.* 7).

112. Puddle linings are occasionally required in sandy soils to prevent excessive percolation; the lining may be applied to the bed alone or to both banks and bed: walls of puddle in the banks alone will not stop much percolation, although they may lessen the danger of breaches.

Wherever puddle is introduced it should be of the best quality and carefully protected from atmospheric influences by a thick earth covering. An ordinary cross section of a puddle lining is shown shaded in *Fig.* 3. When laying the portion on the banks, the workmen should not be allowed to carry the puddle wall in advance of the bank earthwork. For details regarding puddle, see paras. 81 to 84.

113. Before commencing excavation it will be necessary for the engineer to lay down the side widths and land boundaries, both permanent and temporary. These are all fixed by direct measurement from the centre line.

The centre line should be marked with level pegs at 100 feet distances and with bench-marks at every mile. If this is not done it will be impossible to excavate the bed to correct level without the constant use of boring rods, and silt deposits, weeds or erosion of the banks may result.

The pegs should be 12 inches long with a 1½ inch rounded top, and the lockspit should be omitted for one foot on each side of the peg. It is necessary for the pegs to be driven level with the ground so as to ensure the calculations for excavation being correctly made.

114. *Fig.* 5 shows the side widths which should first be laid down. AA for the channel square excavation; BB for the permanent land; CC and C′C′ for the temporary land. The measurements for these widths can be read direct from the Earth-work Tabular form, but it is necessary to leave a berm of at least a 10 foot width between the permanent

Fig. 5.

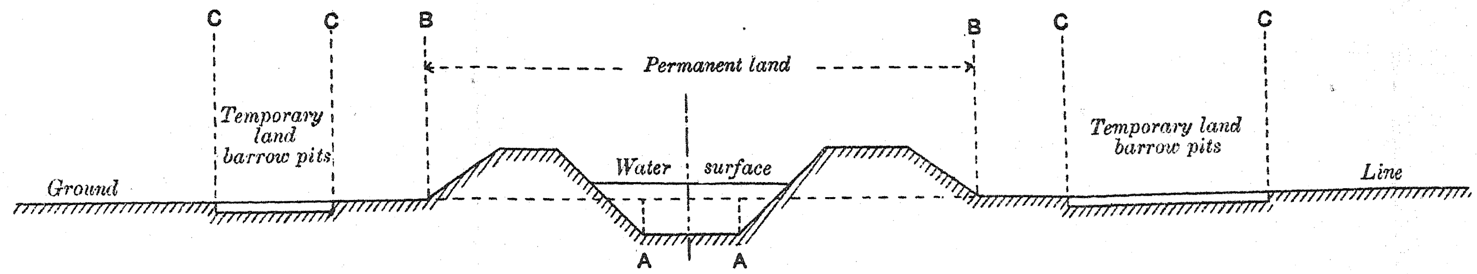


Fig. 6.

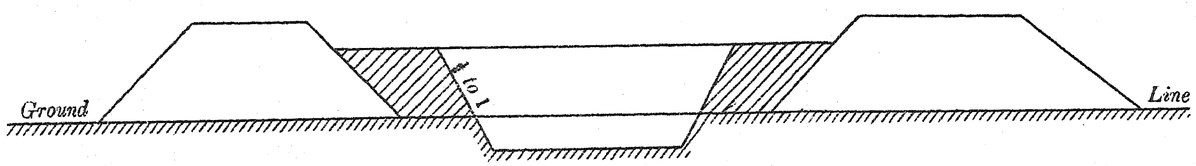


Fig. 7.

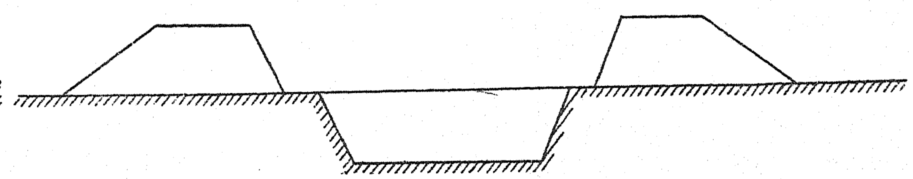


Fig. 8.

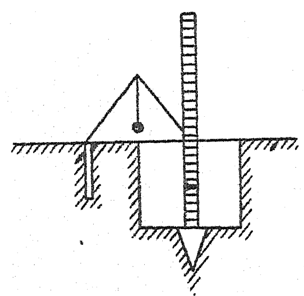
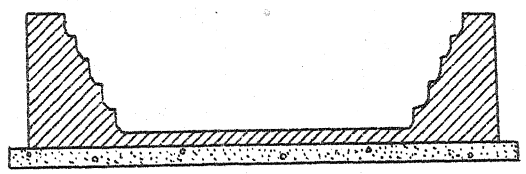


Fig. 9.

CROSS SECTION.



PLAN.

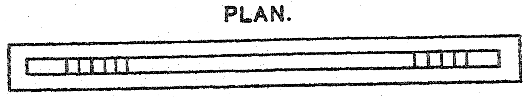


Fig. 10.

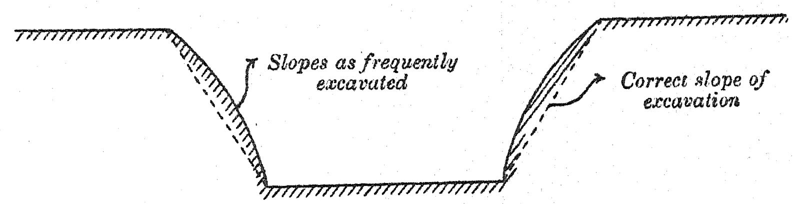


Photo. Zinco., June, 1925.—No. 835 - 20-1500

and temporary land on each side of the distributary. This to is lessen the danger of percolation and to encourage the early ploughing up of the temporary land after the borrow pits have been dug. At the time the side widths for temporary land are being marked, the sites of outlets or openings for village water-courses should be identified from the section, and a width of 10 feet on each side of the water-course centre line should be left free from borrow pits; if this is not done, the borrow pits will require re-filling when the water-course is under construction.

115. Although it is usually unnecessary to acquire more permanent land than that occupied by the channel and banks yet as a strict adherence to this rule would necessitate constant small changes of width, it is best to select a mean width for fairly long lengths, taking care that the banks are always inside the width selected.

To avoid disputes regarding the ownership of permanent land, it will be necessary to fix permanent marks on the boundaries; masonry pillars or stone posts at intervals are often used, but the simplest and most economical expedient is to build the furlong, mile, and other distance marks on the boundary line.

116. All side widths, as well as the centre line, are marked by lockspits: the centre line and the permanent land require trenches at least 1 foot wide by 6 inches deep, the other side widths may be marked with nicks 6″ by 3″ except where the soil is very light or sandy.

117. Borrow pits in temporary land should never be dug more than 1 foot deep; with the distributary line carried strictly on the watershed, and a few side cuts to facilitate drainage, this depth will rarely cause excessive dampness or prevent the land being ploughed up for the first crop which can be sown after the earthwork is completed. Deep, bare, irregular borrow pits detract greatly from the appearance of a new work, particularly when it is borne in mind that they injure the very land which the work was designed to benefit.

Borrow pits 6 inches deep have been recommended, but are unsuited to Indian cultivation, where the upper 6 inches of the soil are generally the most fertile, and 6″ borrow pits are expensive both from the large area temporarily thrown out of cultivation and the long lead this shallow depth involves.

118. It often happens that earth for banks may be obtained from knolls and by levelling irregular ground, where possible, earth should be so obtained for it avoids injury to the land by borrow pits, and often adds to the culturable area near the distributary.

119. The following operations are now required to complete the earthwork of the distributary; they are given in the order in which they should be carried out :—

Transfer of surface levels to the bed.
Making profiles.
Excavation of centre rectangle.
Excavation slopes.
Raising and consolidation of banks.
Dressing and turfing; or grassing.
Check levelling.

120. The surface levels are transferred to the bed according to the depths of digging given in the longitudinal section. A length of 4 or 5 feet of the channel is dug on the square to the proper depth, slightly in advance* of the ground bench-mark or peg, the depth being measured with a levelling rod and mason's square. (*See Fig.* 8).

121. The bed level may be fixed either by a temporary peg or a permanent bed mark; the latter course is the best, because temporary pegs being liable to displacement, will entail the necessity of preservation of the ground level marks for checking purposes until the earthwork is completed, which is often a difficult and inconvenient matter. Although many distributaries have been constructed with half furlong or even furlong bed marks, it is well understood now that bed marks at every 100 feet are advisable for the proper maintenance of the bed levels. Many kinds of bed marks are used, such as stout wooden pegs, masonry or concrete bars, stone slabs clay pipes filled with concrete, etc.

Fig. 9 shows a masonry profile which should be built at half mile or mile distances. It gives the bed width, the bed level, the full supply water level, and it has brick projections on the slopes which mark each foot of vertical height from the bed.

When the bed of a distributary is in embankment, the bed marks should be fixed above ground, and earth rammed round them to prevent disturbance during the construction of the channel.

It is best to fix all the bed marks in the first instance with careful supervision; this can be done with great accuracy, but it is work that cannot be hurried over, and if for any reason it is necessary to push on the construction of the distributary, it may be expedient to fix the permanent bed marks at the mile or 1,000-foot intervals only, and to dig pits to the proper depth at the 100-foot intervals, or to give to experienced contractors a list of the depths of digging.

*This places the bed mark in advance of its true position; this slight error may be accepted or the level pegs may be fixed so as to allow for the deviation in the first instance. The latter method should be adopted where it is possible.

When the permanent bed marks are not fixed at first; they should be put in after excavation of the channel, but before the bed is finally cleared. Mile and furlong stones should always be fixed as soon as possible, for they will be found to be of the greatest assistance during the construction of the work.

122 When the fixing of bed marks has advanced for some distance from the distributary head, a party of experienced labourers may be started on profile work; this consists in cutting the interior slopes of the channel when in excavation for about 5 feet in length opposite each bed mark, and in making up the banks for the same length, as these profiles are intended to act as guides to the contractors when constructing the distributary. Great care should be bestowed on the style and accuracy of the work, the excavated slopes should be neatly trimmed, and the embankments thoroughtly consolidated with the proper slopes. It is a good plan to allow each contractor to make the profiles in the length of distributary he is to construct; he will thus early learn the style of work the engineer expects from him, and gain an insight as to the rates, etc.

Cord * instead of earthen profiles are sometimes employed; they are suitable for high banks, but are liable to displacement, and should be checked frequently.

123. The making of profiles completes the preliminary operations, and when they are ready over a sufficient length of channel the earthwork should be carried on with vigour: this is expedient to avoid the unnecessary occupation of temporary land and to save the time of the supervising establishment, and to ensure the earth being consolidated when it is freshly excavated, and before it has had time to harden. The centre rectangle should first be excavated with vertical sides. (See AA *Fig*. 5) the earth being thrown on the bank space in 6 inch layers, all clods being broken up and grass and jungle removed. If the bank space is covered with thick grass or jungle it should be cleared before the earth is thrown upon it; each 6 inch layer should be laid to the full bottom width of the bank and thoroughly consolidated before a second layer is put on. It is advisable to make each layer extend over a considerable length, and to carry on the earthwork of the bank as level as possible, because short uneven lengths of bank are difficult to consolidate properly. This is particularly necessary where banks are rolled instead of being rammed.

124. When the centre rectangle is completed on a sufficient length, the interior side slopes may be dug out and trimmed. Contractors generally keep their best men for the work; it is difficult to execute neatly,

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*See paragraph 36 of Manual.

but is profitable to the workmen, as the vertical sides can be cut down in lumps into the centre channel. Frequent inspections of the work are necessary to prevent these lumps* being buried unbroken in the banks, but bad work like this cannot be concealed if the rule of long lengths of 6 inch layers is adhered to. When the excavation of the side slopes has been finished the banks are completed to the full height by excavation from borrow pits in the temporary land.

125. In ordinary agricultural land the outside lockspits for borrow pits need only be laid down as the work proceeds; this will allow of many improvements being made by carefully selecting the sides from which to take earth In gardens or valuable land great care should be taken in this respect, and it will be better, and often cheaper in the long run, to carry earth from a long distance and avoid injuring valuable property. Compensation should always be paid for any injuries caused; the amount can generally be reasonably settled on the spot by the engineer personally, or by a trustworthy subordinate.

The best season for outside excavation is after the rabi is cut, finishing in the beginning of the rains; interference with crops will thus generally be avoided and the compensation payable for temporary land be reduced to a minimum. If the outside lockspits for temporary land are not laid down until actually required, the rabi harvest can be cut by the cultivators, and the borrow pits dug, and the land returned to the zamindars in time for the kharif sowing.

This procedure is however impossible on large channels, and here it is advisable to lay out the lines well in advance so that crops are not sown on the land that is required for the work.

126. The banks at works should not be thrown up until the masonry is completed and passed; this is particularly necessary for small works such as outlets, and it is advisable to omit from the earthwork contract certain lengths of bank where masonry works are to be built, and to include them in the works estimate at special rates.

127. Water is sometimes run into a new channel which has been blocked at intervals with earthen bunds, the water can then either be baled up on to the banks or led along their tops in narrow channels

* When work is carried on in a dilatory manner, particularly in warm weather, the soil exposed to the hot wind gets very hard, and lumps carelessly allowed in the banks cause frequent breaches of the distributary, in time the banks get sound up to normal water level, but every unusual rise of water surface finds weak places, necessitating frequent and expensive repairs, and it sometimes takes years to put a badly constructed bank into good condition.

After the banks have been thoroughly soaked they can be trimmed off to the proper section. The water standing in the channel may injure the inside slopes a good deal, necessitating a second dressing off, but this small expense will be amply repaid by the compactness the banks will attain and the rapid growth of grass on them.

When plenty of water is available, it may be used to irrigate the temporary land before the borrow pits are dug; this will improve the banks if the earth is rolled and rammed before it dries.

128. Distributary banks should be neatly dressed off to the proper section, and maintained so until grassed over. The expense of turfing is prohibitive for small sections, but a good growth of *dub* grass can generally be ensured by watering the new banks and weeding them carefully, during the hot weather and rains. When the *dub* grass is well established, the banks should be let for grazing throughout the year. Grass cutting should also be encouraged, as this process improves the *dub* growth and kills off other grasses. Some canal officials object to cattle being allowed on distributary banks, but it will be found that their trampling consolidates the banks, and the saving of the cost of annual jungle clearance will more than cover the expense of repairing the slight damage they do.

Grazing, with ample facilities provided for traffic crossings and watering, will do much in the way of preserving distributary earthwork in sound condition.

129. The care that has been shown in selecting the supply of earth for banks during construction, should be continued in taking earth for maintenance and repairs in after years. Earth for strengthening banks or closing breaches should be taken from borrow pits dug outside those used for construction, on no account should the old pits be deepened. Holes or breaches in the banks should be opened to the full depth, and the sides or slopes stepped back before being refilled. Ramming in 6-inch layers should be insisted on, and water freely used for consolidation, and all clearances from the channel, instead of being thrown on the banks or berms should be deposited and levelled off the old borrow pits.

130. The difficulty of correctly and expeditiously estimating and measuring up the earthwork and land over long lengths of distributary, at every 100 feet, is very great, and the work cannot be economically carried out by the regular earthwork tables or by highly paid establishment. A tabular form is appended which can be used with advantage after a little instruction by two clerks working together. A few examples are worked out to show the system. One clerk taking the longitudinal section in hand, reads out to the second clerk the entries for

columns 2, 3, 10 to 12 and 14; an entry of 3 will be necessary at every peg where the bed is below ground; 14 can only be entered where the bed is embanked, which will seldom occur. 2, 10, 11, and 12 only require noting in the form where these dimensions are changed in the section. After the entries are made they should be checked over, and then the economical digging can be calculated out by trial for every change in any of the dimensions 2, 10, 11 and 12, if this column has not already been filled up as a guide to the engineering of the channel. (See paragraph 105).

When the depths of digging are equal or above what is economical, it will not be necessary to carry the calculations beyond column 8, as the economical depth provides sufficient earth for the banks.

The remaining columns involve simple calculation. Columns 8 and 21 only require one entry each for every 1,000 feet.

The land widths can be written down directly from inspection.

From the above, the procedure for calculating by this form may appear lengthy, but in practice it is very simple and straightforward work, and most of the entries will be found of great assistance when the work is being set out on the ground.

EARTHWORK AND LAND FORM.

———————— *Distributary*, ———————— *Canal*. ———————— *Page*

Number of Station.	INSIDE. Bed width.	Digging.	Areas. B × D.	Slopes 1 to 1.	Total.	Distance.	Contents.	Economical Digging.	OUTSIDE. Bed to Bank.	Top width of Bank.		Top width over all B + 2H + L + R.	Ground to Bed.	Ground to Bank {H − D or H + E.	Areas. W × G	Slopes 1½ to 1.	Total.	Deduct Channel.	Balance.	Contents.	WIDTH OF LAND. Temporary.	Permanent.
	B	D	B × D	SD²					H	L	R	W	E	G	W × G	SG²		(B + H) H				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	10	4·5	45	20	65	100		4·5	7·5	8	6	39	...	3·0	117	14	131	131·3				48
2		4·6	46	21	67																	
3		4·9	49	24	73																	
4		5·1	51	26	77																	
5		4·8	48	23	71																	
6		4·9	49	24	73																	
7		4·8	48	23	71																	
8		4·8	48	23	71																	
9		4·5	45	20	65																	
1,000		4·3	43	18	61		69,400		7·5	8	6	39		3·2	125	15	140	131·3	8·7	870	9	
1		4·4	44	19	63									3·1	121	14	135		3·7		4	
2		4·3	43	18	61									3·2	125	15	140		8·7		9	49
3		4·5	45	20	65																	
4		4·7	47	22	69																	
5		4·6	46	21	67																	
6		4·8	48	23	71																	
7	9·75	4·5	44	20	64			4·5				38·75										
8		4·5	44	20	64																	
9		4·5	44	20	64																	
2,000		4·5	44	20	64		65,200													1,240		
1		4·7	46	22	68																	
2		4·9	48	24	72																	
3		4·9	48	24	72																	
4		4·9	48	24	72																	
5		5·0	49	25	74																	
6		5·0	49	25	74																	
7		4·8	47	23	70																	
8		4·8	47	23	70																	
9		4·6	45	21	66																	
3,000		4·5	44	20	64		70,200															
1		4·6	45	21	66																	
2		4·6	45	21	66																	
3	9·6	4·5	43	20	63			4·5														
4		4·3	41	18	59				7·5	8	6	38·6		3·2	123	15	138	128·3	9·7		10	
5		4·2	40	18	58									3·3	127	16	143		14·7		15	48
6		5·8	56	34	90																	
7		5·6	54	31	85																	
8		5·1	49	31	80																	
9		4·8	46	23	69																	
4,000		4·5	43	20	63		69,900															
1		4·3	41	18	59				7·5	8	6	38·6		3·2	123	15	138	128·3	9·7	2,440	10	
2		4·0	38	16	54									3·5	135	18	153		24·7		25	
3		3·8	36	14	50									3·7	142	21	163		34·7		35	50
4		...	...	...	...								6	3·1	312	98	410		281·7	In tank	282	63
5		4·1	39	17	56									3·4	131	17	148		19·7		20	
6		3·9	37	15	52									3·6	138	19	157		28·7		29	
7		4·0	38	16	54									3·5	135	18	153		24·7		25	
8		4·5	43	20	63																	
9		4·8	46	23	69																	
5,000		4·8	46	23	69		52,600													42,390		
Total,						...	327,300													46,940	473	50
Brought forward,						...																
Grand Total,						...	327,300													46,940	473	

APPENDIX I.

See page 25, para. 37.

Practical method of obtaining side widths on sidelong ground.

Draw to a large scale on a separate sheet of paper, a type section.

Fig. 32.

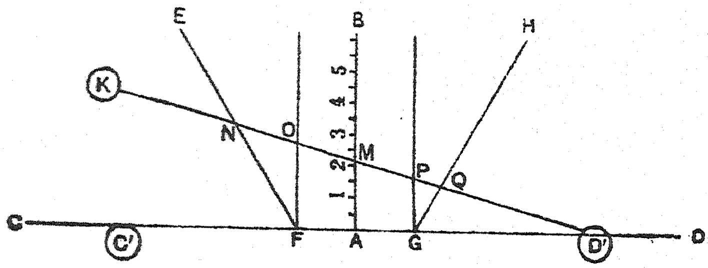
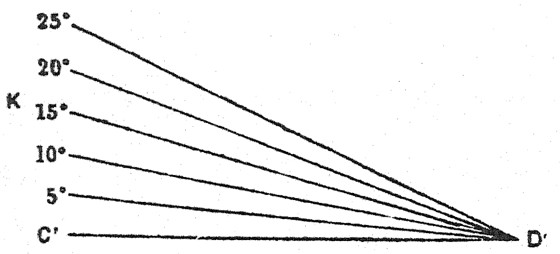


Fig. 33.



EFGH (*Fig.* 32) of the cutting to be laid out; on which FG represents the horizontal portion, and EF, GH the side slopes. From the centre A draw the veitical line AB, and graduate it to feet and tenths, on the same scale as the section.

Fig. 33 is a separate scale of degrees drawn from the origin D′. This should be drawn on tracing cloth, in order that it may be placed over *Fig.* 32 and seen through. The slope of the sidelong ground has of course been noted in the survey for each peg. Or if this work is done in the field, the slope of sidelong ground is measured at each peg as the work is laid out.

Now suppose D′K (*Fig.* 33) to be the slope of the sidelong ground for which side widths are required, and MA (*Fig.* 32) the depth of the cutting: then by placing the transparency (*Fig.* 33) over the section (*Fig.* 32) so that the line C′D′ coincides with C′D′ and moving the tracing along this line CD till the point M (*Fig.* 32) (which indicates the depth of the cutting at this point) touches the line D′K (*Fig.* 33), a figure NFGQ will be formed, representing the actual section of the required cutting on the sidelong ground having the slope D′K, with a depth equal to MA below the centre peg M. The side widths MN, MO, MP and MQ, can then be measured off by scale, and the distances thus obtained pegged off on the ground. The scale will of course be that to which the type section EFGH has been drawn.

This work should, if possible, be done in the office ; but it can also be done in the field.

For an embankment the reverse arrangement will give the side widths as shown in

Fig. 34.

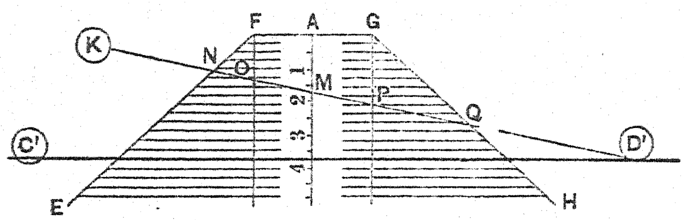


Fig. 34.—It will be only necessary to draw a number of parallel lines on the type section to assist in adjusting the tracing ; when D'K will represent the slope of the sidelong ground, MA the height of the embankment, and MN, MO, MP, MQ the required side widths.

If the ground slopes in the opposite direction, it would simply be necessary to reverse the tracing, which, being transparent, could be used with either side uppermost.

APPENDIX II.

Specifications for earthwork and puddle.

NOTE.—Paras. 1 to 21 are written in general terms and include most of the points which have been entered in the specifications of recent large works in the United Provinces.

Preliminary.

1. Before the commencement of a work the centre line, the earth lines and borrow pit lines must be laid out neatly, on the ground, and then the ground must be thoroughly cleared of all trees, jungle and (in the case of bunds) of roots and whiteants' nests.

2. In the case of embankments all hollows or holes in the ground must be filled in with the greatest care before the rest of the work is commenced. The earth should be thoroughly powdered, the layers should not exceed 3″ in thickness and must be thoroughly rammed and watered, so that any subsequent settlement may be avoided.

3. The method of procedure in the case of embankments which are required to hold up water is that after all trees, jungle and roots have been removed, and all hollows filled, the ground surface should be specially prepared before the bank proper is commenced. Where there is grass, the surface soil should be removed, where there is sand or loose stone they must be removed, and in all cases the ground should be roughened by picks or ploughs. Steps must always be cut in the ground where there is any slope, this is also sometimes necessary on level ground.

4. Before the work is commenced ten feet wide profiles of the actual work to be done must be made at furlong distances. When the ground is uneven, or when there is any change in the section, a greater number of profiles must be made.

The proper allowance for settlement (see paragraph 10) must be given in all profiles.

5. Before work commences the *matams* which are to be left in a cutting should be marked. In embankments and in deep cutting the centre line or edge of the work must be demarcated outside the work in such a manner and in such a position as may be decided on by the Executive Engineer in charge. This is done so that at any time the work can be realigned.

Work in embankments and excavation.

6. All embankments and cuttings must be constructed in accordance with the type sections and levels on the plans, after making the proper allowance for settlement. (See paragraph 10).

7. All banks must be laid in even layers that do not exceed 12″ in thickness and should be slightly concave in the centre. When the soil is not light loam, the thickness must be reduced. When kabar or mar soil is used the thickness of each layer must not exceed 6″.

Any clods which come in from the borrow pits must be broken, jungle removed from the earth, and the work well rammed before the next layer is commenced.

Work must proceed evenly throughout the whole length or reach of the bank. In a big work it is impossible to keep the whole length at one uniform level, but every endeavour should be made to keep the work as uniform as possible.

8. In high embankments there must be a distance of 50′ between the toe of the bank and the borrow pits. The first 10′ width of borrow pit must only be dug to a depth of 1′, the next 10′ width to 2′ and so on. All clods must be broken up, and jungle and loose stones removed before earth is taken from the borrow pits. Borrow pits for ordinary canal or road banks must be placed at a distance of at least 20′ from the boundary of the permanent land taken up for the work.

9. Earth removed from cuttings and laid on spoil banks need not be laid in even layers, nor need the clods be broken, but the spoil banks must be made of uniform height with 2 to 1 side slopes and with the top surface sloped outwards to prevent drainage flowing towards the excavation. When spoil banks are required at the edge of a canal roadway, 10′ wide drainage openings must be made through the spoil bank and properly graded to allow the drainage from the canal road to run off.

10. In hard clay and black cotton soils an allowance for settlement of at least 3″ in every foot of height must be made. In light soils at least 2″ and in sandy soil 1″ must be allowed. The exact amount for each site will be settled by the Executive Engineer in charge after actual experiments.

11. Where a bank is made of two kinds of earth the layers of both must progress uniformly.

12. Where new and old banks are joined, or where a bank meets a hillside the old work must be stepped carefully with an easy slope.

13. Where a breach has to be filled in in an old bank which has completely settled, the sides of the old work must be carefully cut into easy steps with a slope not less than 1 in 3, and the new earth must be laid with the greatest care, so that there should be a minimum of settlement. Earth must be thoroughly broken up and laid in 3″ layers, rammed tightly and flooded with water.

14. During the rainy season, and also when the bank has been completed, the top surface must be divided into small compartments with earthen ridges, to enable all rain that falls to soak into the soil and accelerate subsidence.

These ridges must be kept repaired throughout the rains.

15. *Puddle.*—Dry puddle must be made with good brick soil in which there is a little dampness. The earth must be thoroughly powdered and then laid in layers which do not exceed 3″ in thickness. It is then rammed very tightly, and water sprinkled over it with a rose (if necessary) to enable proper contact to be made with the next layer.

16. Wet puddle is made with soil containing a large percentage of clay. The earth must be broken up and soaked with only a sufficiency of water to enable it to be kneaded with the feet. It must be twice turned with the spade and rekneaded before it is used. As this puddle will crack badly if it is allowed to dry, it should only be used in places where it will always remain damp.

17. *Earthwork in connection with masonry works.*—The excavation for foundations must be in accordance with the plans, sections, etc., and care must be taken that the bottoms of the trenches are level, both longitudinally and transversely, and that no excess excavation is done.

18. The bottom of the trenches must be watered lightly and then rammed, and any holes or defects must be dug out and refilled with concrete, or filled up in any other way which may be ordered by the Executive Engineer in charge.

19. All material removed from the foundation trenches must be placed at a distance of at least 2′ from the outer edge of trench.

No masonry work must be commenced till the completed excavation for the foundations has been inspected by the Executive Engineer in charge.

20. When the masonry work has been carried to 1½′ above the ground surface, the space between the masonry work and the excavation trench must be thoroughly cleared of all débris, and then filled in with earth laid in 6′ courses, well watered and rammed. In very deep foundations the earthwork filling should be carried out as described above after every 4′ in height of new masonry work.

21. On completion of the masonry work the site must be cleared, all débris removed and the earth dressed off to correct section.

APPENDIX III.

Excavation for foundations in rock and earth.

Earth in channels and embankments.

Note—This appendix has been taken from the Handbook of Professional Orders in the Irrigation Branch, United Provinces.

1 *Excavation for foundations.*—Before excavation is commenced the work is to be lined and pegged out on the ground by the officer in charge.

2. Bench-marks consisting of rectangular blocks of masonry, with the top surface plastered, should be built so far outside the work as to avoid the possibility of disturbance. On these the alignment of important lines, such as centre line, the outer faces of a bridge, lines of abutments, piers, etc., should be marked by a fine line scored in the plaster. The more important bench-marks should have their reduced levels cut into the plaster and filled with black lead.

3. The width of the excavation depends on the character of the material to be excavated, and this should have been determined by trial pits or borings before the estimate is drawn up. Ordinary earth above spring level will stand at a slope of 1 to 1 while below spring level a slope of at least 1 in 5 is usually required.

4. Rock must be properly prepared to receive the foundation courses by levelling its surface, either by breaking down in equalities, or by filling up cavities with concrete or masonry. Any portions of the rock which present indications of having been shaken or injured by any disintegration should be removed

5. The surface of the rock prepared as above should be perpendicular to the direction of pressure of the superstructure.

If the whole of the foundation cannot be brought to one level, the rock must be stepped so that the bottom foundation courses throughout may rest on a surface perpendicular to the direction of pressure.

6. The bottom of foundations in earth, if above spring level, should be thoroughly flooded with water so as to prove the soundness of the foundation before any of the foundation courses, whether of concrete or masonry, are begun.

7. If the excavation has been made too deep, the excess depth is on no account to be filled in with made earth, but the void is to be sloped or stepped back and filled with concrete.

8. In excavation below spring level arrangements are necessary for keeping down springs, so that there may be no stoppage of excavation owing to water rising in the foundations.

Springs may be kept down by baling, hand pumping, or more generally on canal works, by pumps driven by steam power.

9. In using a steam pump a small well, built of second or third class bricks in mortar, should be undersunk clear of the space to be occupied by the bottom foundation courses, and to a depth of 3 feet below the level to which the foundations are to be excavated.

At vertical distances of 1 foot apart, feed holes should be built of bricks in mud which are opened as required, after the well has been sunk to the required depth.

The pump is fixed on the well on a wooden frame at a level which is determined by the selection of a suitable position for the portable engine by which the pump is driven, but it should not, if possible, be more than 20 feet above the water to be lifted, though this height may be exceeded in extreme cases. There should be space between the footvalve of the pump and the sides of the well sufficient to allow a man, with a short-handled *phaora,* to work freely round the footvalve.

10. When springs are too strong to be kept down by baling, though the bottom level of the foundations is not more than 4 or 5 feet below spring level, the pump may often be erected on a trestled frame round the bottom of which planks are nailed, so as to form a well in itself. The frame is then undersunk in the same way as a masonry well.

11. In all cases water pumped or baled must be led outside the work and well away from the foundations.

12. Before pumping or baling is begun material in excess of that required to bring the work above spring level should have been collected, and all necessary arrangements to ensure rapid and continuous progress should have been completed.

13. *Earthwork in channels and banks.*—Before commencement of the work accurate profiles of embankment, excavation and spoil should be made at every furlong, or if the ground is uneven, at every half furlong ; and lockspits should be laid down marking bed widths, side slopes, roadways, banks, etc.

14. Bench-marks of masonry should be fixed at every furlong along the centre line at bed level in channels and roadway level in embankments, and a list of depth of digging, height of bank, and a drawing of the cross section of channel bank, etc., should be supplied to the contractor, at whose expense any error in carrying out the work according to specification be made good.

Supplementary bench-marks should be fixed on the plinth of every milestone on the edge of the permanent land, and their reduced levels should be carefully recorded on the longitudinal section.

15. All channel excavation is to be taken down vertically for the bed width of the channel or for such less width as may be ordered.

16. All earth from the excavation thrown up on the roadway or banks should be treated as specified for embankment. All clods or lumps of earth are to be broken up in the excavation pits.

17. Earth surplus after completion of roadway of bank, should be thrown up in spoil banks and dressed off in accordance with the profiles.

18. The dressing of the side slopes of the channels should not be begun without receipt of definite sanction from the Sub-divisional Officer, and should be executed in exact accordance with the profiles.

Any portion of the work where too much earth has been cut away should be cut back in steps and treated as for an embankment.

19. Before commencement of work on banks the ground should be cleared of all grass, roots, mounds, etc., and where so ordered, the top spit or mould should be removed on one side till completion of the work, when it should be spread evenly over the side slopes.

20. When the earth from the excavation is insufficient for the bank, earth may be taken from borrow pits either in the canal bed or outside the permanent land.

21. Borrow pits in the bed of a channel are objectionable in many ways, and should as far as possible be avoided, but in some cases they constitute a less evil than external borrow pits. When permitted, precautions must be taken to prevent retrogression of levels in the bed of the channel. The depth of the borrow pits should not exceed 3 feet, nor should their length be greater than 1½ times the bed width of the channel. A bar not less than 10 feet wide at the top should be left between adjacent pits, and a berm not less than 6 feet wide should be left along the toe of each inside slope. The sides and ends of the borrow pits should either be sloped or stepped 1 to 1.

22. The depth of earth to be taken from outside borrow pits should be one foot, except in special cases where a maximum depth of 4 feet may be sanctioned. In such special cases the land for borrow pits must be acquired permanently. All excavation from outside borrow pits should be commenced from the outside edge of the land taken up for them, and in no case should excavation be permitted within 20 feet of the permanent land taken up for the channel and its embankments, etc.

Where practicable, it is preferable to leave a strip of from 50 to 100 feet between the outside edge of the permanent land and the inside edge of the temporary land. This will slightly increase the cost of lead, but it will insure the borrow pits being brought under cultivation, and will amply repay the small additional outlay, by neutralizing the wastage of water from water-courses. In distributaries excavation from borrow pits should not be begun until the positions of outlets have been fixed; and no excavation should be permitted within 50 feet on either side of the water-course.

23. When outside borrow pits are required, inside borrow pits should not also be specified, all the earth required being got from outside.

24. Earth thrown up on banks must be free from clods, grass, roots and all rubbish, and should be consolidated in layers not exceeding one foot in thickness.

Earth layer should be consolidated with square wooden rammers weighing not less than 8 lbs., or where possible by flooding it with water before a fresh layer is thrown up.

The earth is to be thrown from the sides towards the centre and not *vice versa*.

Each layer is to be made slightly concave to catch rain that may fall.

25. The banks should be made up layer by layer of the above thickness and in such lengths as may from time to time be fixed, and until any one layer is completed and passed by the Sub-divisional Officer or competent authority deputed by him, a second layer should not be begun.

In no case should any contractor raise the bank to a greater height than 3 feet until the work has been passed, and definite sanction is given to him to proceed.

26. All banks should be thrown up of a width at least one foot greater on either side than the final section. In dressing the slopes this excess width will be cut back to the final section the surplus earth being utilized in raising the bank to full height. No dressing of the slopes should be begun without definite sanction.

27. After completion of any portion of the work a trench should, if ordered, be cut through the bank at any points selected by the Divisional Officer, to ascertain if the specification has been strictly adhered to. Such trench should be dug out and refilled according to specification at the contractor's expense.

28. Puddle where specified or ordered, should be made of good firm clay worked up with water to the consistency of dough. It should be put down in six-inch layers and well pugged with the feet, care being taken to work it close up to any masonry

behind which it is being laid. Puddling should advance simultaneously with the earth work by which it is backed, and should never be more than one foot higher than the earth work layers.

If only fat clay is procurable, clean sand in such proportion, determined by experiment, as may be required to keep the puddle from cracking, is to be mixed with the clay. The sand in all cases should be thoroughly pugged into the clay before it is laid in the work.

APPENDIX IV.

Digger's task and number of carriers required.

Note.—This appendix has been taken from the United Provinces Revised Famine Code, 1912—Appendix CX.

A.—EARTHWORK.

Table of the digger's task excavation only.

Soil.	Daily task in cubic feet.		Remarks.
	Ordinary.	Low	
1	2	3	4
Soft soil such as sand	200	150	
Light soil, such as sandy loam	150	100	
Medium soil, as loam or marl	110	80	
Hard earth and clay	80	60	
Stony soil and black cotton soil when dry ..	80	60	

(*b*) The task adopted represents one day's wage of a male digger and it thus fixes the pure digging rate for the working on the basis of the grain price adopted. The pure digging rate then varies with the kind of soil and the grain price. The remainder of the rate is made up of the cost of carrying and in road work there are usually more carriers (*i. e.*, persons only fit for carrying) than are required for the work. In such cases the more able among the C and D class workers should be utilized for digging as far as possible; and if there is still a surplus of carriers the feeble and emaciated among them should be put on to breaking clods and dressing the work.

In work involving a long load it is important carefully to adjust the carriers to the quantity of earth which has to be carried and this should be done as follows:—

(*c*) The reduced lead of the work in hand should be taken as—

$$^{*}R = 72 + H + 12\,(V-3).$$
$$= 36 + H + 12\,V.$$

Where R = reduced lead in feet;

H = horizontal lead in feet;

And V = vertical lift in feet.

* NOTE.—This formula is adopted from the report on famine works by Sir Thomas Higham, K.C.I.E., Inspecter-General of Irrigation, a member of the Famine Commission of 1898.

Thus, if earth has to be lifted 10 feet and carried a distance of 100 feet from the digging pit, the reduced lead = 256 feet.

A carrier unit will be taken as 10,000 cubic feet carried over a reduced lead of one foot. Then the simple rule is to divide 10,000 by the "reduced lead," and the result gives the number of cubic feet which should be carried by each carrier unit. Thus in the above case each carrier unit should carry away 39·06 cubic feet of earth, and if the soil was of a kind that required a digger's task of 110 cubic feet, then each digger should have $\frac{100}{39}$ = 2·8 carrier units, or a gang of 13 diggers should have 36 carrier units.

(*d*) An ordinary woman or man in class C is counted as a carrier unit, but children between 10 and 14, class D, are counted as half a unit. Thus in the above case a gang containing the average proportion found on many works in 1897 would consist of 13 men capable of digging, 3 inefficient men, 21 women and 13 children between 10 and 14 years, and it would have $3+21+13\times\frac{1}{2}=30\frac{1}{2}$ carrier units, and hence the carriers could not do their work.

It would be necessary to turn two of the least efficient diggers into carriers: there would thus be less earth dug, amounting to the work of probably more than four carrier units, and there would be two more carriers to remove the earth, which would correct the proportions. If the same gang were employed on a road with a lift of five feet and mean horizontal lead of 50 feet, the 13 diggers would only require 21 carriers, and in that case five of the class C workers should be placed among the diggers, the gang as a whole being debited with only a two-thirds' task for each of these less efficient diggers.

(*e*) In checking the correctness of the proportion of carriers to the diggers of the gang the simpler way is to multiply the gang's total digger task by the "reduced lead," and divide the product by 10,000; this will give the correct number of carrier units for the diggers under these conditions.

APPENDIX V.

Settlement.

Experiments were made in every canal division in Bundelkhund during 1914-15, to ascertain the correct allowance that should be given for settlement for various kinds of soils. A few of the results are given below. The experiments were made as follows:—

(1) A small plot of land was levelled, then a square pit 5′×5′ was carefully marked out, and dug with vertical sides to a depth of 1 foot.

(2) The contents of this pit, given in column 2, were placed on a cloth which was spread close to the pit. All the clods were broken to a gauge of 2 inches.

(3) The loose earth on the cloth was measured in a wooden box of 1 cubic foot capacity, and the quantity is recorded in column 3.

(4) Column 5 shows the quantity of loose earth which was required to refill the pit, the earth being rammed in a similar manner to the actual work on a bank.

The amounts which are now accepted are:—

Light and very sandy soil	..	..	1½ inches per foot of height.
Ordinary light soil ..	..	..	2 ,, ,, ,, ,,
"Mar" soil which breaks easily ..		..	2½ ,, ,, ,, ,,
"Kabar" soil ..	..	..	3 ,, ,, ,, ,,
Extra hard kabar soil	..	..	3½ ,, ,, ,, ,,

Details of a few experiments made.

Nature of the soil experimented upon.	Contents of pit experimented upon.	Loose earth equal to solid earth in column 2.		Quantity of lose earth required to fill the spit.	Rammed earth equal to solid earth in column 2.		Remarks.
		Quantity in cubic feet.	Settlement per foot in inches.		Quantity in cubic feet.	Settlement per foot in inches.	
1	2	3	4	5	6	7	8
Dark yellow clay ..	24·17	31·63	3·7	25·85	29·5	2·65	In Mirzapur district.
Light yellow clay (a very powdery earth) ..	25·1	31·61	3·12	29·43	26·95	0·88	
Black cotton ..	24·98	38·28	6·39	29·94	31·94	3·34	
,, ,, ..	25·0	38·5	6·48	29·5	32·63	3·66	
Red soil ..	25·0	31·0	2·88	28·0	27·68	1·28	
Kankary soil ..	25·0	33·0	3·84	28·0	29·46	2·14	In Jalaun district.
"Parwa" light soil ..	25·0	33·36	4·01	28·76	29·0	1·92	
Kabar soil	25·9	34·68	4·64	27·81	31·18	2·96	
Mar soil	25·0	32·48	3·99	27·18	29·87	2·33	
Kabar soil	23·95	37·29	6·68	29·3	30·48	3·27	In Hamirpur district.
Kankar soil ..	23·27	32·64	4·32	26·95	28·18	2·53	
Parwa light soil ..	24·68	31·16	3·12	27·39	28·18	1·7	
Mar soil	24·31	31·6	3·59	26·69	28·78	2·21	
Light soil	25·0	36·4	5·47	31·5	28·9	1·87	In Banda district.
Kankary soil ..	25·0	35·2	4·9	30·0	29·3	2·06	
Kabar soil ..	23·77	33·6	4·96	27·0	29·57	2·9	

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